"WE'RE GETTING ONLY

3 cylinder sleeve barrels

PER HOUR "

A FEW years ago as men count time, but virtually a decade in an industry as young as aviation, a builder of aeroplane engines faced a serious problem. Shop production of finished cylinder sleeve barrels was only three an hour! Slow machining...troublesome grinding...high shop losses and plane builders calling for engines. ■ Where was the trouble? In the steel? In the heat treatment? In the machining? In the grinding? ■ In the plant of the engine builder, in the shops of the forger and in America's largest metallurgical laboratories, Republic metallurgists studied the problem. They were not long in finding the answer, these men who had whipped many a stubborn problem in the pioneer days of the automotive industry. ■ A special analysis steel requiring only normalizing was developed...quenching was eliminated ...a change was made in the Brinell specification...a formed forging replaced an extruded one. ■ Result? A better cylinder sleeve barrel—and production jumped to seventeen an hour! ■ From three an hour to seventeen ...a boon for the engine builder...a milestone for the industry...but only one of hundreds of similar accomplishments by the metallurgical staff of the world's largest producer of alloy steels. ■ If you use steel in your product or manufacture, the helpful services of Republic metallurgists are at your disposal. Write us.

Metal
Progress

Owned and Published by

American Society for Steel Treating

Table of Contents

Timken Alloy Steels
Made where users' needs are understood

The selection of the right grade of alloy steel for and specific purpose is the basis of successful performance. This is the first care of Timken technicians when faced with a new problem.

It involves a thorough understanding of service conditions and fabricating requirements from the user's viewpoint in order that the steel may possess the proper combination of abilities. A slight difference in formula may make a big difference in results. This is where Timken's user-maker experience counts.

The weight which certain steel sections will be called upon to carry, the shock they must endure, the degree of wear resistance they must possess, their carburizing and heat treating requirements and machinability—these and all other properties are carefully analyzed and their relative importance accurately determined.

Then Timken metallurgists are in position to select the most suitable grade of steel with certainty.

The maintenance of this pre-determined grade, and the satisfaction which it indicates, are assured by the skill and experience of the Timken personnel and complete modern facilities of the Timken steel plant, plus the Timken system of quality control. It will pay you to buy your steel where users' problems and needs are so well understood.

THE TIMKEN STEEL AND TUBE CO., CANTON, O.
Detroit   Chicago   New York   Los Angeles   Boston

GOOD WILL BASED ON GOOD STEEL

BOOTH No. B-53
National Metal Exposition

TIMKEN
Electric Furnace and Open Hearth
ALLOY STEELS
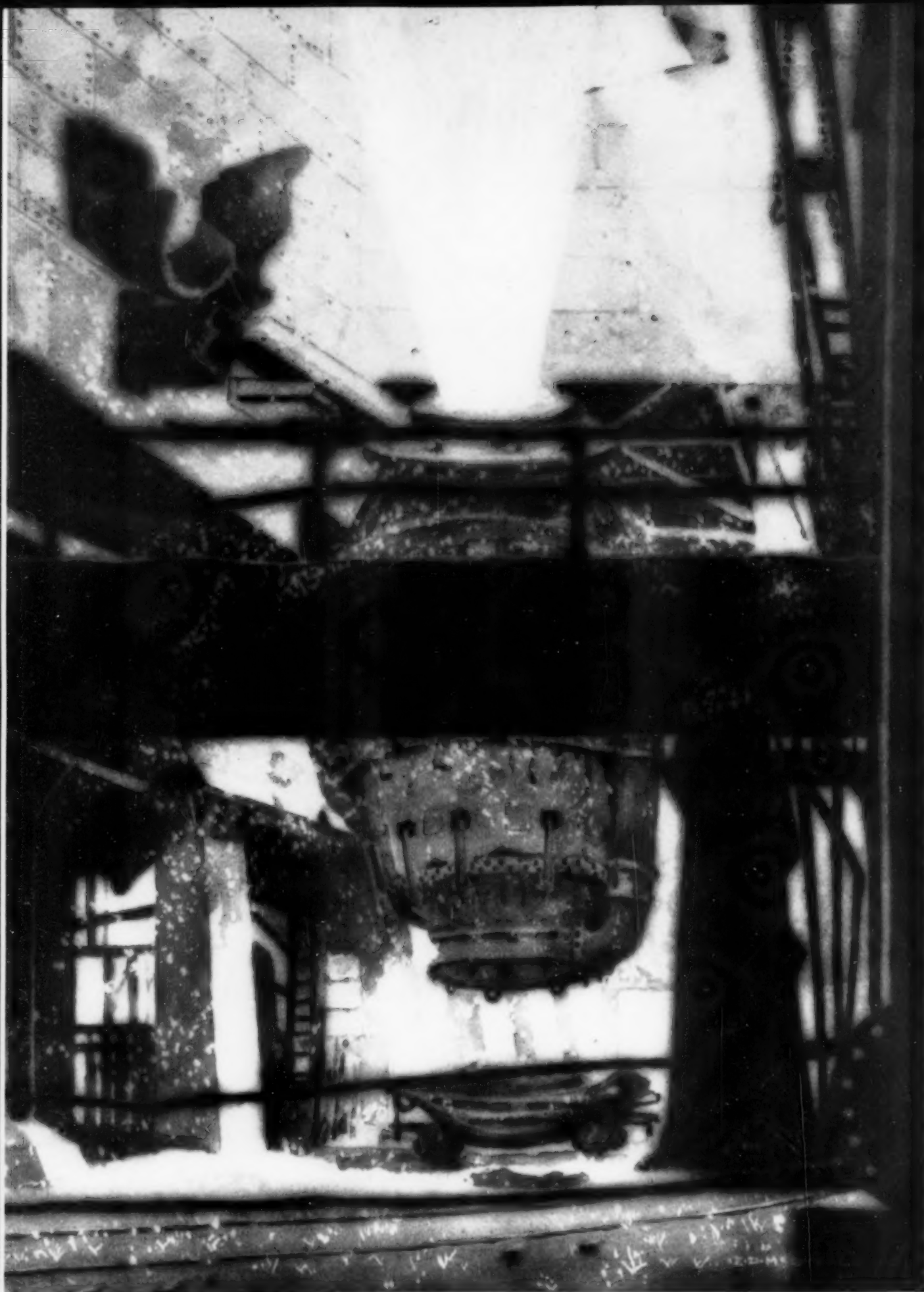
From Water Color by Edward D. McDonald

A Bessemer Blow

Steels

made

without manganese

By Capt. S. B. Ritchie
Watertown Arsenal

MANGANESE is classed by the War Department as a strategic material; that is, a material that is not available in this country in suitable quantity and form to supply the needs of the steel industry in a national emergency were our supply from abroad shut off, and for which there is no adequate substitute. Work was therefore undertaken at the Arsenal (under the stimulating interest of Gen. T. C. Dickson, commanding officer, and the cooperation of the laboratory staff) to investigate the manufacture of steel suitable for cannon without using any manganese. It was assumed that this would be the worst condition ever to be met, although it was realized that the ability to pass the minimum requirement for gun forgings (60,000 lb. per sq.in. proportional limit, 90,000 lb. per sq.in. ultimate strength, 18% elongation, 30% reduction of area, and 24 ft-lb. tensile Charpy impact — all transverse specimens) does not necessarily mean that the steel is suitable for the manufacture of cannon.

An editorial in June METAL PROGRESS outlined the studies which have led to the belief that zirconium might replace manganese in steel, as far as its functions of neutralizing oxygen and sulphur are concerned. We therefore made a total of seven heats in our high frequency induction furnaces in the department established for casting guns by the centrifugal process, using the practice which we have found admirably adapted to the latter purpose.

For melting in these furnaces, all the charge is generally added at the start except a small amount of final deoxidizer, which is added just before the pour. In the heats now to be described about one-half the zirconium addition was made at the start and the balance five to ten minutes before pouring. In order to reduce as far as possible any inclusion of manganese, Armco iron was used as the base charge, with wash metal and ferro-alloys to give the desired composition. The furnace was sealed with a cover over the top to exclude air during the melting period.

Ladle analyses show these heats to vary but slightly, recovery of alloys being very good. The range and average losses were:

Carbon	0.29	to 0.36%	loss 0.08
Manganese	0.05	to 0.08	
Silicon	0.21	to 0.31	loss 0.16
Sulphur	0.013	to 0.017	(volumetric)
Phosphorus	0.009	to 0.018	
Vanadium	0.10	to 0.16	loss 0.02
Molybdenum	0.25	to 0.33	loss 0.01

Gas analyses of the centrifugal castings showed 0.004 to 0.009% oxygen, 0.0002 to 0.0008 hydrogen and 0.006 to 0.017% nitrogen.

The recovery of zirconium was much less than might be expected. However, the Armco iron used in the charge was high in total oxygen content. No slag other than that formed from the furnace lining and the charge was used, and it is possible that some of the zirconium

was lost by oxidation from the air. A dark stiff slag heavier than usual was formed on the heats to which zirconium was added.

The first heat (No. 173) had no zirconium. The rest, except the last, had 0.25 to 0.28 added, but the metal analyzed 0.02 to 0.05. In the last heat (called C-218 for the purposes of identification) 0.69% Zr was added, but again the metal contained only 0.03%.

It is difficult to understand why with an addition of some 69 points of zirconium the recovery is no more than when 25 points is added. The carbon loss averages between 8 and 9 points and the silicon loss between 16 and 17 points. The normal loss in these furnaces is around 6 points carbon and 5 points silicon. The loss of silicon is far less than that of the zirconium and points to the fact that zirconium is a much more powerful deoxidizer than silicon. It would also appear that zirconium is alloyed with some difficulty.

Of the seven heats, three (No. 173, 239, and 249), weighing 375 lb. each, were made in a furnace with 500 lb. capacity and cast in a $6\frac{1}{2}$-in. square ingot. No. 263 was made in a $2\frac{1}{4}$-ton furnace and cast in a 5,000-lb., 21-in. fluted ingot. Three (C-207, C-209, and C-218) were made in a 1,000-lb. furnace and made into 690-lb. centrifugal castings for 75-mm. pack howitzers.

All the ingots gave normal piping with no indications of purging. Heats 239, 249, and C-207 showed signs of wildness in the test spoon and required additional silicon and zirconium to kill them. The ingots were stripped hot, buried in cinders and allowed to go cold before reheating for forging. The castings were also cooled in ashes before heat treatment.

Forging of Ingots

The heats to which zirconium was added showed no indications whatsoever of red-shortness. Forging in one case was carried as far as 24 to 1 reduction. Normal heating and soaking times were applied to the ingots in an oil-fired furnace, the maximum temperature used being 2,150° F. and the minimum slightly above the critical. Forgeability over this range, using press and hammer, appeared to be as good as any ordinary alloy steel. Hot working

Illustrations On These Pages Represent Sections of "Manganese-Free" Ingot No. 239 and Forging Made From It

Alongside is macro-structure, full sized, of bottom of ingot, after cropping. Pickled 40 min. in a simmering mixture of HCl and H_2SO_4

At top of page 37 is similar full sized section of ingot forged 3 to 1 to 4-in. round

Microstructure is of transverse test bars cut after the forging had been normalized from 1,700° F., quenched from 1,607° F., and drawn at 1,200° F.
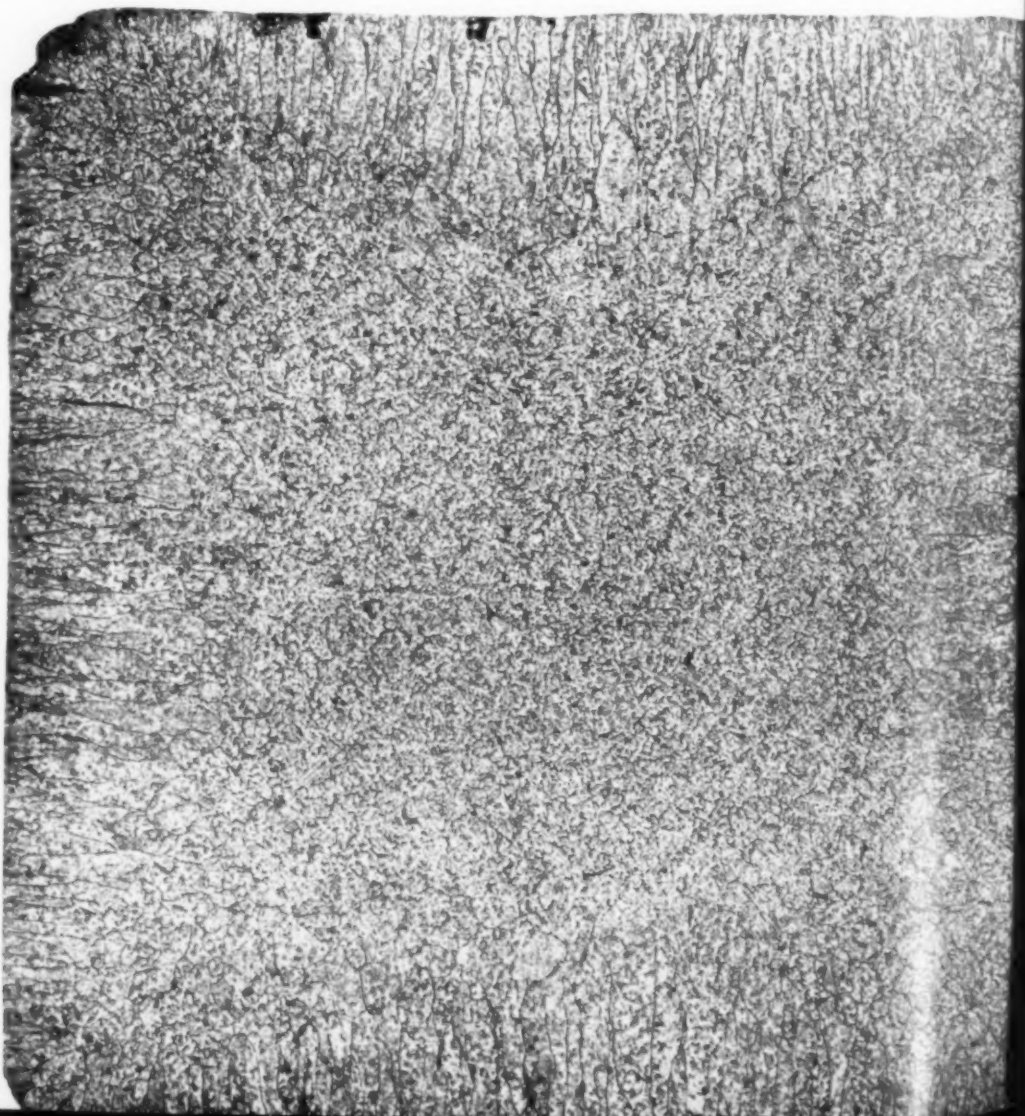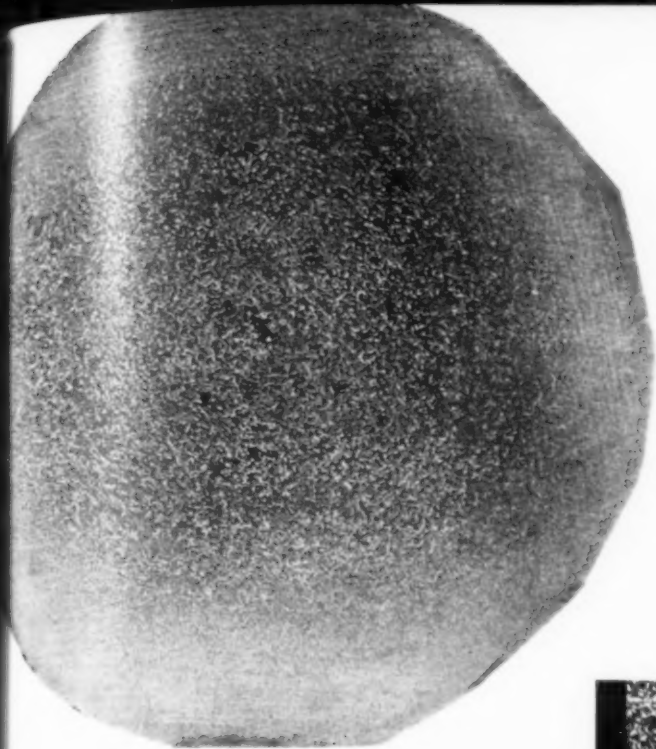
The two 6-in. ingots containing zirconium were also forged 3 to 1 into 4-in. rounds; the macro-etched top of No. 239 is shown on the immediate left. (These two ingots showed a striking similarity. A material quite rapidly attacked by the etching solution has been removed, disclosing a coarse columnar structure.)

Physical tests were cut after heat treatment; namely, normalize from 1,700° F., water quench from 1,607° F., and furnace cool after a draw

was carried out under a variety of conditions and no trouble of any kind was experienced.

Normal discards for ordnance steel of 30% from top and 5% from bottom were made in each case, and macro-etched discs were taken from the inside ends of the discards. The etching solution consisted of 38% HCl, 12% H_2SO_4, 50% H_2O by volume, maintained at the simmering point for 40 min. during immersion.

Forgeability of No. 173, containing low manganese and no zirconium, was unsatisfactory; it was somewhat red short. It was forged to a 4-in. round, and a section about 8 in. long from the best part of the bar taken for heat treatment. Brinell hardness readings taken after normalizing and quenching showed the material to be soft at one end and hard at the other end.

Quenching from 1,740° F. gave the nearest approach to uniformity in hardness (217 to 255). The response to hardening was certainly abnormal and unsatisfactory, but the tensile properties were very good. Longitudinal bars from the quenched untempered bar, midway center to outside, gave the tensile properties: 75,000; 111,500; 22.0%; 57.2%.

In respect to external appearances this ingot was as good as any made. Pronounced ingot structure was in evidence and the hot acid etch disclosed a selective action apparently around the grain boundaries.
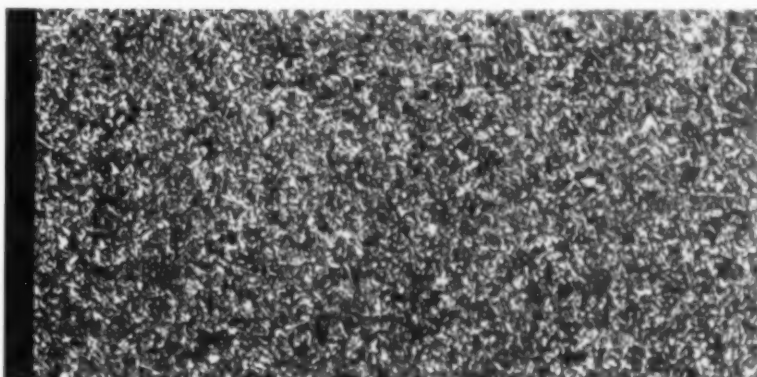
at 1,200° F. Charpy tensile impact values were obtained from a 0.550-in. round bar turned with a 60° V-notch with 0.312-in. diameter at the flat bottom of the notch.

About 32 test pieces were cut from center, mid-wall, and surface of heat treated bars which gave satisfactory agreement. Average results of longitudinal bars were 76,500; 100,300; 24.0%; 62.6%; and 31.4 ft-lb. For the transverse bars the average values were 81,500; 106,500; 24.6%; 62.9%; and 32.7 ft-lb. For a slightly higher draw (1,290° F.) the impact value is slightly lower, while the reduction of area remains approximately the same and the elongation increases. Furthermore, the transverse bars appear to give as good ductility as the longitudinal test bars.

Large Ingot

As the small ingots gave satisfactory results, a $2\frac{1}{2}$-ton ingot, No. 263, was cast in a 21-in. fluted mold. Usual discards were made and the ingot forged 2 to 1 to 14-in. round under a hydraulic press.

Some slag inclusions are in evidence at the

top exterior of the ingot. The columnar structure, so evident in the small ingots, is absent. Perhaps the much slower cooling has either caused diffusion or prevented the formation during solidification of the material so readily etched away from the grain boundaries. The slag referred to above is still in evidence in the 14-in. round and has caused a few surface imperfections. No chipping was necessary in forging the ingots containing zirconium.

Tensile properties of this forging were not satisfactory, even after a variety of heat treatments. The impact values were erratic and in most cases exceedingly low. Microstructure of test bars is not that of a well-hardened steel but approaches more nearly to a normalized condition; there are also traces of ingotism. It

Lower Two Macrographs Are Muzzle and Breech Ends of Centrifugal Casting C-218 of "Manganese-Free" Steel for 75-mm. Pack Howitzer. Immediately below is structure of muzzle after double normalizing, quenching and tempering

appeared necessary either to develop a better heat treatment, or to give more hot working, or both, in order to obtain higher impact values. It was felt that mass effect was a serious factor and that a more drastic quench would be necessary.

Accordingly, bars 1¼ in. thick were cut transversely from a 4-in. disc already studied and given various heat treatments. Best and most uniform results were secured after a quench from 2,012° F., and two draws, one at 1,245 and one at 1,275° F. Hardness then ranged from 223 to 248; tensile tests were satisfactory (81,000; 106,000; 20%; 60%) but the Charpy tensile values ranging from 7.1 to 11.8 ft-lb. were still too low. Microstructure appears to be rather coarse-grained, strongly cleavaged sorbite; no appreciable amount of ferrite is found in the grain boundaries.

It was then decided to ascertain if further hot working would raise the impact value, so the bar was reforged in steps down to a 5 to 1 reduction (9.5 in. diameter). Discs 4 in. thick were water quenched from 1,920°, then in iced brine from 1,740° F., and drawn at 1,200° F. Surface hardness then varied from 241 to 269; test bars cut from them were 228 hard but still had low impact values.

A block from the original forging was then reduced 15 to 1 to a ¾-in. bar. It was normalized after 1 hr. at 1,740° F., water quenched after 1 hr. at 1,607° F., drawn after 1 hr. at 1,200° F., and redrawn similarly at 1,275° F. Hardness was 228 and the tensile tests averaged 97,000; 114,000; 24%; 65%; and 45 ft-lb. A ¾-in. slab from the 9-in. bar (5 to 1 reduction), heat treated as noted, also gave high Charpy tensile impacts, averaging 34 ft-lb.

The microstructures of a test specimen from the ¾-in. heat treated bar and from the ¾-in. heat treated slab are the best of any examined;
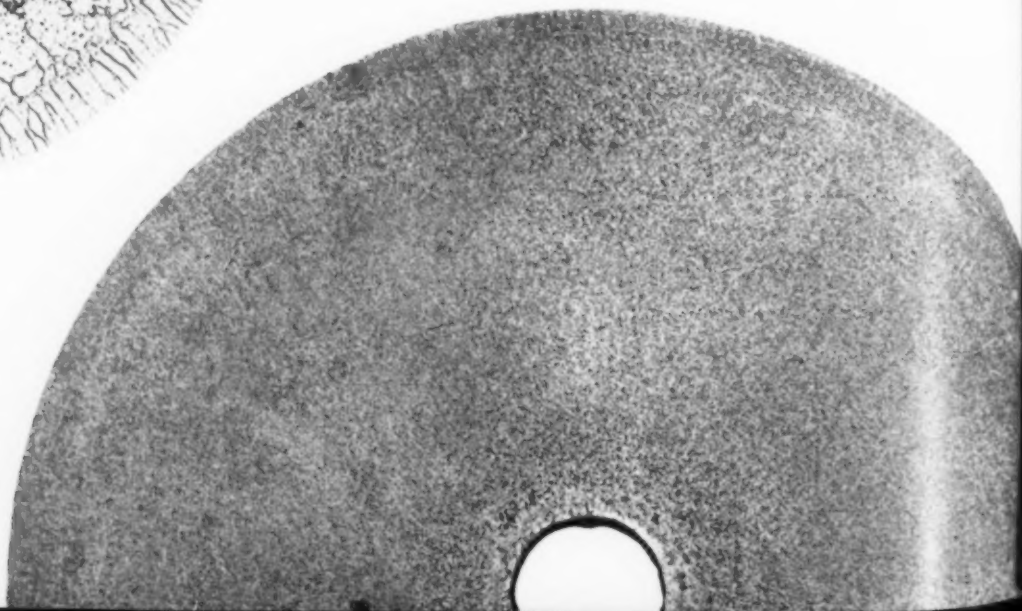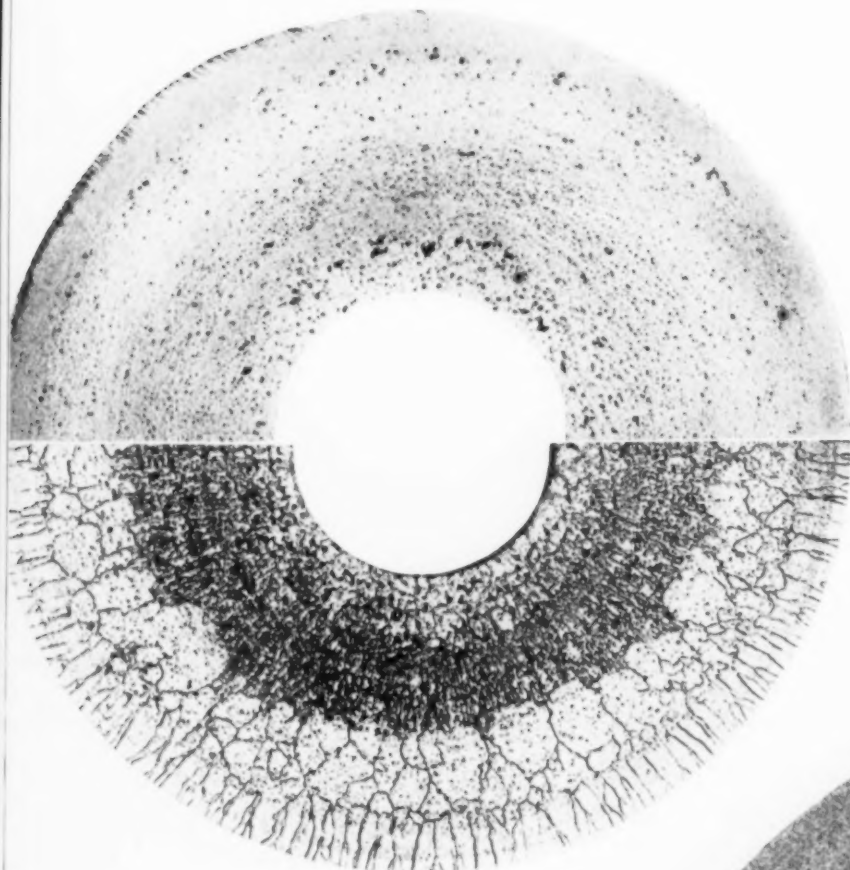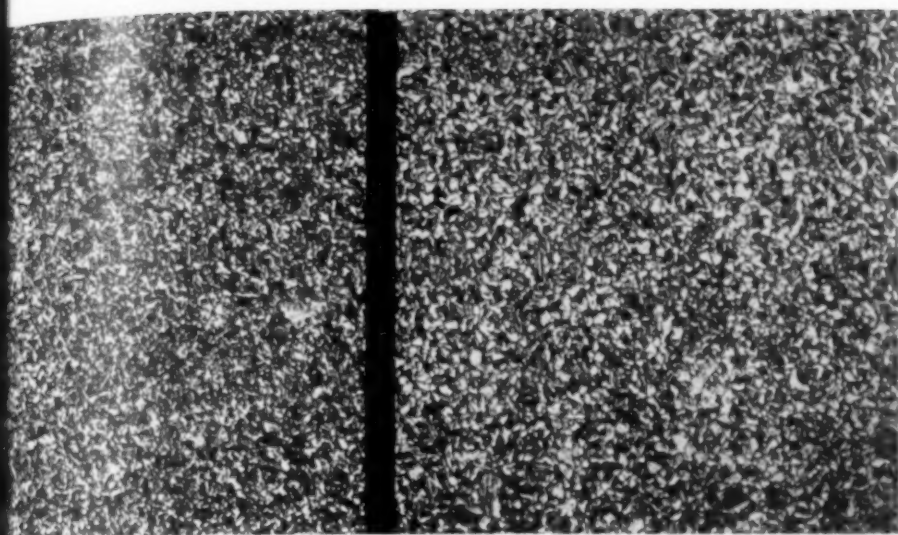
Muzzle End   Breech End

Microstructure After Heat Treatment of Casting Illustrated on Opposite Page (100 Diameters)

they are quite alike and show very fine-grain uniform sorbite with no segregations or free ferrite. The bar that received the 15 to 1 reduction has perhaps a slightly finer structure than the other, and this is revealed in the better impact value. The excellent results indicate that the quenching temperatures first used for the 5 to 1 forgings were too high.

Consequently, another 4-in. disc from the 9½-in. round was heat treated as follows:

> 1,920° F., 4 hr., water cooled to black heat, remainder in air
> 1,740° F., 4 hr., drastic quench in water
> 1,607° F., 2 hr., quench in water
> 1,320° F., 2½ hr., cool in water.

The slab had a surface hardness of 228 Brinell; transverse test pieces cut from it mid-length at various radii had hardness of 196 to 187, and the tensile tests were satisfactory for gun forgings (71,000; 96,000; 26.5%; 61.8%; and 10 ft-lb.).

Centrifugal Castings Without Manganese

One prime reason for this work was to ascertain if a steel could be made without manganese, cast centrifugally, and heat treated to meet the gun forging requirements.

A tube for the 75-mm. pack howitzer was selected for trial. As cast the tube weighs about

690 lb., has a breech diameter of 8 in., a muzzle diameter of 4.5 in., and is 81 in. long. The bore, as cast, is approximately 1 in. Casting conditions, such as speed of rotation, rate of pour, and temperature of the chill mold, were the same as for ordinary production.

Macro-etched discs taken 6 in. from the muzzle ends have a pronounced similarity to that of ingot 239; the view on the left page shows two different concentric structures, an inner and an outer. This structure is peculiar to this composition.

Sections 7 in. long were cut from breech and muzzle end of C-207 for heat treatment, which consisted of:

> 1,740° F., 3 hr., air chill
> 1,607° F., 4 hr., water quench
> 1,290° F., 4 hr., furnace cool.

Transverse test bars taken on various radii across the wall at breech and muzzle gave very low ductility. Fractures of most of the test bars giving poor ductility, especially at the muzzle end, showed large conchoidal silvery surfaces, apparently the outlines of the grains shown in the macro-etch. Discs cut from these same heat treated sections showed identical macrostructure to that of the untreated casting. Evidently, the treatment had failed entirely to refine the coarse structure. High normalizing temperature is required to break down and diffuse the material that etched away so rapidly from the grain boundaries.

This material under the microscope gave the appearance of oxide streaks. With a drastic normalize it seemed to disperse throughout the grain. A number of temperatures were tried, and while possibly not the best, an air chill from 2,100° F. followed by one at 2,012° F. seemed to break down all traces of the original coarse grain structure, as shown in the macroprint of casting C-218 on the opposite page.

After this treatment, discs from the muzzle ends, quenched from 1,607° F.,

By William B. Stout
President, Stout Engineering Laboratories
Dearborn, Mich.

Small Sky Cars

entirely of metal

IN THIS day of all-weather flying when planes and pilots have got to the point where almost any day is a flying day, structural considerations have become more and more important in aircraft.

There was a time not long ago when planes were fair-weather vehicles, and certain structural members were considered admissible even though their strength was either too low for safety or of undetermined amount. However, some of the lessons of the last few months have brought about the realization that the structure of an airplane, and particularly of its wings, must be such that its strength can be absolutely determined. For this reason, wood in airplanes has recently taken a very definite back seat. Especially since the Rockne tragedy (which occurred in a plane whose wings had wooden ribs) there is a renewed effort on the part of most firms in aviation to employ metal construction.

One vital difference between metal and wood structures is illustrated in some of our recent testing. In one experiment a wooden wing spar was crushed in the testing machine to a certain breaking point. At the time the wood failed its strength went down to zero, and any plane with this type of wing would have been completely through. In comparison we tested an extruded duralumin spar as used in the airplane designed for the Buckley Aircraft Co. of Wichita. This spar, of the same weight as the wooden piece, failed at approximately the same compressive force, but at the end of the test the piece had been bent into the shape of the letter "S" and was still supporting 10,000 lb. In a plane built of such material there would have still been a possibility of getting down safely to earth if the wing was overstrained.

No one can inspect wood and tell what strength it is, particularly after it has stood in the crate or inside a boxed wing structure for a number of months; with metal an engineer can determine the strength to within 5%. For this reason, and for reasons of lightness as well, we have recently chosen metal for the entire structure of the Sky Car, the two-passenger monoplane which we are building.

This article is not to discuss the merits of the small plane, nor its anticipated field, but rather its metal construction and the reason why a sky car, designed for private owners to fly safely with the fewest possible lessons of preliminary instruction, should be an all-metal construction. If flying is to be widely adopted for business and pleasure the vehicles must be fitted with every possible precaution that can add to safety, whether engineering, metallurgical, or psychological. One of the important mental precautions, and one which is very

closely related to sales, is the obvious added safety of metal construction and the greater security the purchaser feels in buying a plane which in appearance suggests the strength that it actually has.

Spars of the Sky Car are made of extruded duralumin T-sections riveted into a cantilever truss girder, tapering from the center out to each tip. The vertical and diagonal members of the truss are made of channel sections riveted into place. Sand loads on these spars for test show much less deflection per unit load than can be obtained in wood, and since rigidity is the great problem of the airplane wing (even more than strength, which is easier to obtain), this is an

which we followed in our original experience. At first there is the lure of smooth metal, like the outside of an automobile body, and each designer is convinced that he can produce a flat metal structure light enough in weight. The history of flat metal for wings, however, has always been the same. The reason is simple enough to be explained with an ordinary sheet or writing paper, which is about the thickness of metal that is used on wings if they are rightly designed and constructed.

It is obvious, of course, that a sheet of paper has no strength in compression, though it does have surprising strength in tension. Roll this same sheet of paper up into a tube of an inch
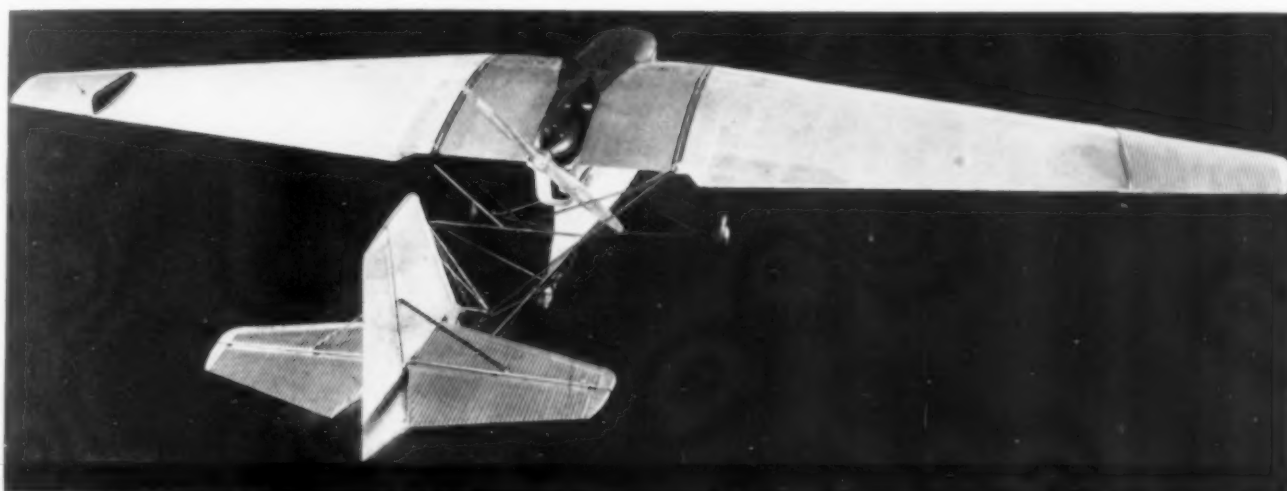
Rear View of the Small, All-Metal Plane Designed by the Author for Private Pilots
Photographs Courtesy of "Aero Digest"

important reason for the adoption of metal construction.

Wing coverings of cloth are liabilities in the matter of structural strength. When the fabric is laid and stretched tight with wing dope, its own tension deducts many pounds from the actual strength of the wing structure. When metal is used throughout, the skin of the wing is a part of the whole and is stressed to its proper modicum of work together with the rest of the material employed.

Development of this type of structure has extended through many years of concentrated effort and by the expenditure of several million dollars. It is interesting to note how the usual experimenter in metal follows the same line

diameter or thereabout, and the actual weight it will carry is astounding. And so when we build a metal wing, if we take the thin sheet and corrugate it along the line of the air flow, since each corrugation is the section of a tube, it becomes a rib, or strength member, with one hundred times the compression possibilities of the flat sheet.

For this reason, the working of flat sheets over the wings of a plane where the surfaces are fairly flat means that a heavy gage of material must be used — much heavier than is required for tension load — so that when planes are built with the wings of flat metal, the weight always mounts beyond expectations and to a point which does not compare favorably with either
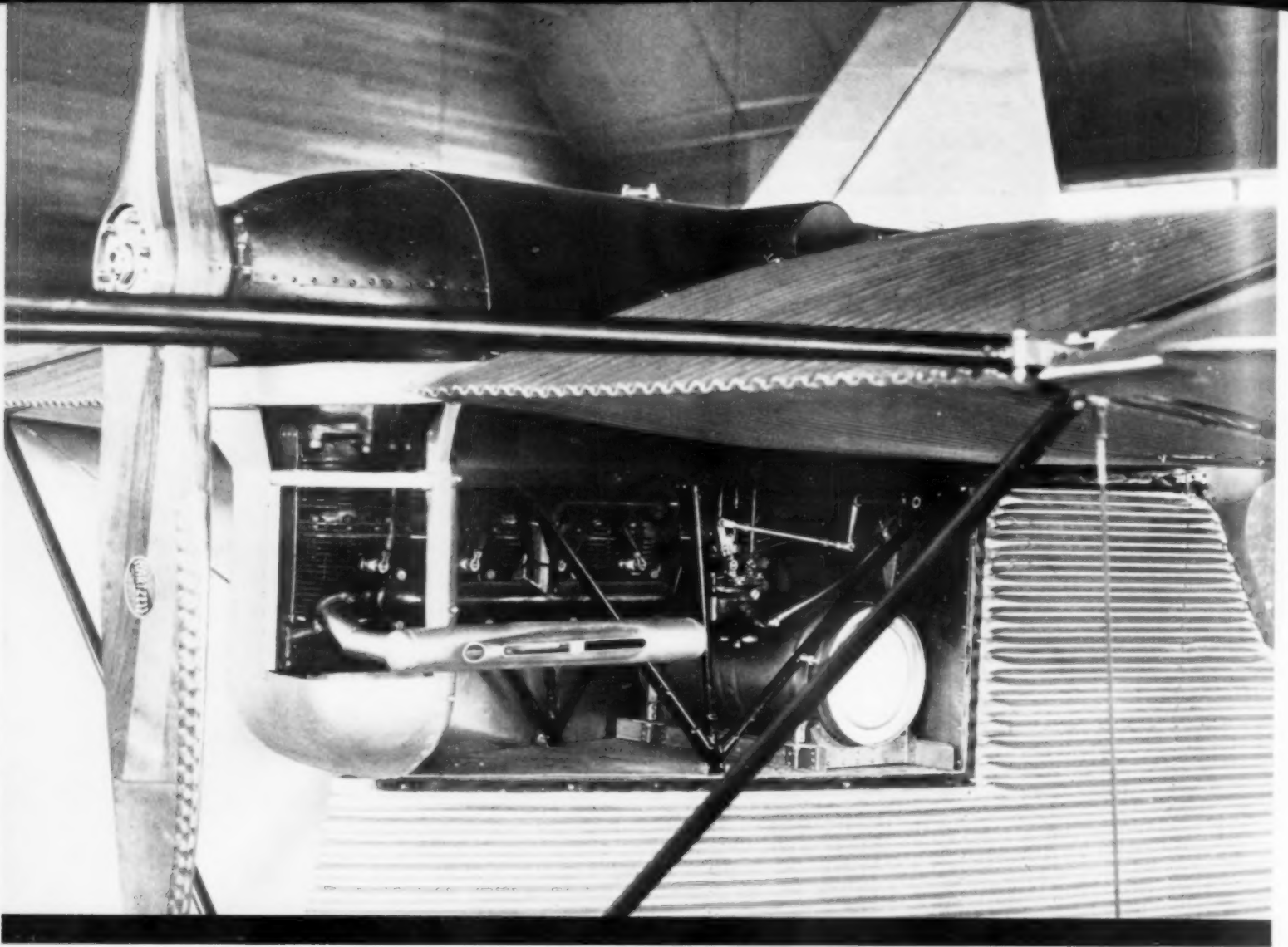
Engine Mounting of the Sky Car. The inverted, four-in-line air-cooled engine is placed behind the cabin, insulated by a firewall. This position makes the cabin relatively quiet and free from fumes and smoke. The propeller pushes the plane, rather than pulls it as in most ships

cloth wings or corrugated wings from the strength-weight comparison basis. A round fuselage capable of being built on tubular curvatures can be made of smooth skin without running into undue weight, but our wing structures are entirely built of corrugated metal. These wings, which carry a load of 7.4 lb. per sq.ft., weigh themselves just over 1 lb. per sq.ft.

Metal Lends Simplicity

Another advantage of metal construction is the simplicity of fabrication. Of course, there are a lot of rivets, but once we learned how to put them in, they did not prove to be particularly expensive. They always give warning of overstressing so that there are no breakages from vibration. I am not ordinarily in favor of welded assemblages for major members, such as spars or fuselages, on account of the present

near impossibility of inspecting the final weld. Rivets, I believe, are more easily repaired in this type of craft in the field, are more reliable, give warning of weakness, require much simpler shop equipment, and are understood and repaired all over the world.

Another important item in favor of rivets is that the entire plane can be made with one class of workman. In the old-type airplane shop different buildings or departments are required for different processes, each employing different types of labor — wood-workers, cloth-workers, tinsmiths, welders, painters, riggers, wire splicers, seamstresses and machinists. In the making of metal airplanes, even the most complicated part of the structure can be put together with ordinary riveters of comparatively short training, working under a well-developed system and in jigs which make dimensional mistakes impossible.

Corrugated Duralumin Sheets and Chromium-Molybdenum Tubing Are the Principal Materials Used. The dural is riveted; the tubing welded

It is my belief that metal planes can be built in quantities in about half the floor space required for the present-day cloth, wood and steel tube plane of equal size.

Welded chromium-molybdenum tubing for engine mounts, skid parts, longerons (the longitudinal fuselage members) and certain other parts has proved very satisfactory in airplane work. In early, and particularly in military designs where cost was not a primary object, a great many fittings were also made of welded steel patterns, a procedure which ran into very high expense but was satisfactory when assembling only a limited number of ships on a single order or design.

In the work we are planning with the Sky Car with the prospect of volume production, quite a bit of magnesium has been used in minor fittings where the section of the metal is large enough so corrosion was not a problem. These alloy castings, of an extremely high strength-weight ratio, are used for aileron and control hinges, foot pedals, bell cranks, and such items, and not only save weight but also contribute to the reliability of both the materials and the structure of the airplane.

Undoubtedly the future of air travel depends on increasingly better materials. Metals, such as duralumin, magnesium, and alloy steel, seem ahead in this field because of their intrin-sic merit and because of the continual research sponsored by their manufacturers. The purchaser, who will fly his own car, will demand metals in it just as he gets in his present automobile, and the manufacturer must use them in order to get accuracy. The sooner the airplane industry approaches this problem seriously and produces what the public wants rather than what they want to make the public accept, the sooner will the aircraft industry occupy its deserved place in the transportation schemes of the so-called "average man." Automobile makers have known this for years.

Safety Features of the Sky Car Include Clear Vision, Third Wheel to Prevent "Nosing Over," and All-Metal Construction

By F. R. Hensel,
Metallurgist,
and E. I. Larsen,
Assistant Metallurgical Engineer,
Westinghouse Research Laboratories,
East Pittsburgh, Pa.

dissolved

nitrogen

embrittles

Weld

Metal

METALLIC arc weld deposits are, according to their chemical analysis, nearly pure iron. Their behavior, however, differs greatly from that of pure iron in that their physical properties can be changed considerably by suitable heat treatments. They also possess age hardening properties, which is an indication that they are not pure metals, but metastable solid solution alloys.

In the arc welding process, oxygen and nitrogen, the two main constituents of the air, are ionized and enter the deposited metal either in the form of oxides and nitrides or through absorption by the molten steel.

In recent years the problem of the influence of gases upon the physical properties of metals has been studied by a number of investigators (as summarized by E. W. Ehn on page 59) and it is hoped that the results of this paper are another step in the direction of solving this problem definitely. The influence of nitrogen upon the properties of welds is still much discussed, although recent investigations have thrown more light upon it. That the iron-nitrogen system is an age hardening system is evident from the tentative diagram shown on page 62 of this issue of METAL PROGRESS.

Most of our tests were made on pads obtained by a deposition of commercial bare welding wire. A few tests were made on commercially available arc welds in V-notches prepared by special processes and by the use of special coatings.

Typical chemical analyses of the pads of material studied are shown on the next page.

*Hardness-Time Curves of Quenched Arc Welds.
Maximum hardness is at room temperature in three days*
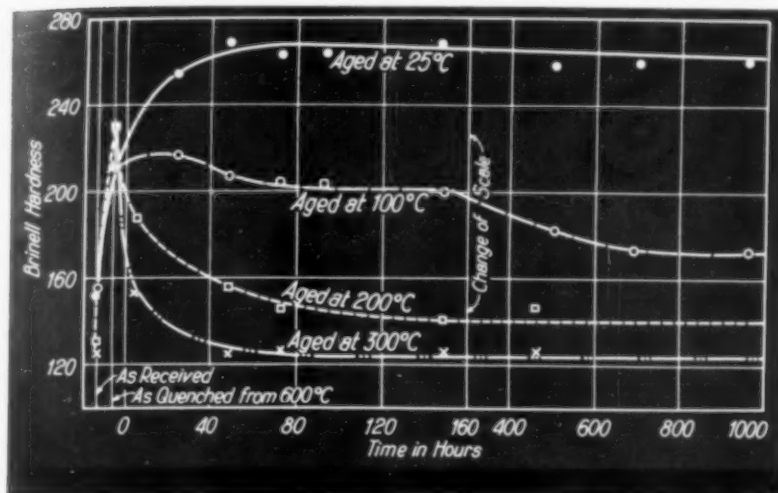
Analyses of Welded Pads

	Bare Arc	Oxy-Acetylene	Atomic Hydrogen
Carbon	0.027	0.033	0.033
Silicon	0.004	0.003	0.008
Manganese	0.006	0.14	0.15
Sulphur	0.03	0.021	0.008
Phosphorus	0.016	0.027	0.005
Aluminum	0.006	0.006	0.009
Tungsten	....	....	0.26
Oxygen	0.259	0.054	0.053
Nitrogen	0.127	0.013	0.017
	0.147 (a)	0.024 (a)	0.037 (a)
Hydrogen	....	....	0.005

Gas analyses in the above tabulation were made by the vacuum method by N. A. Ziegler of Westinghouse Research Laboratories, except the ones marked (a) which were determined by E. W. Beiter who made use of Nessler's reagent in his tests.

According to the iron-nitrogen diagram, arc welds would have to be heated to about 600° C. to be well within the alpha-solubility range before quenching in order to develop fully their age hardening properties. As a result of aging the constituent Fe_6N will be precipitated in sub-microscopic dispersion and cause embrittlement of the metal by blocking the slip planes and thereby obstructing the plastic yielding which would ordinarily occur.

In order to determine the proper quenching temperature for the bare arc welds, a pad of the material having an original Brinell hardness of 100 was quenched. Tempering at the indicated temperatures gave the following hardnesses: 300° C.: 110 Brinell hardness; 400° C.: 112;

500° C.: 135; 600° C.: 183; 700° C.: 175; and 900° C.: 165 Brinell hardness.

Therefore samples were quenched from 600° C. and tested after various aging temperatures and times as shown in the diagram at the head of this page. The maximum hardening effect occurs at room temperature. Aging in ice gave the same results as aging at 25° C. The greatest hardness is reached after approximately 50 to 60 hr. and no appreciable change of hardness occurs with further aging. Higher aging temperatures produce no increase in hardness above that reached by quenching and the hardness decreases slowly at 100° C. aging temperature, more rapidly at 200° C., and extremely rapidly at 300° C.

The effect of different quenching temperatures on the hardness reached during aging at room temperature was also studied. Aging for 200 hr. at room temperature after quenching from 700° C. gave a hardness of 225; the sample quenched from 800° C. hardened to 220 Brinell, and from 900° C. hardened to 200 Brinell.

Aging hardness curves of five commercial

To Improve Arc Welds Materially (From an Age Hardening Standpoint) Nitrogen Must Be Reduced Below 0.05%
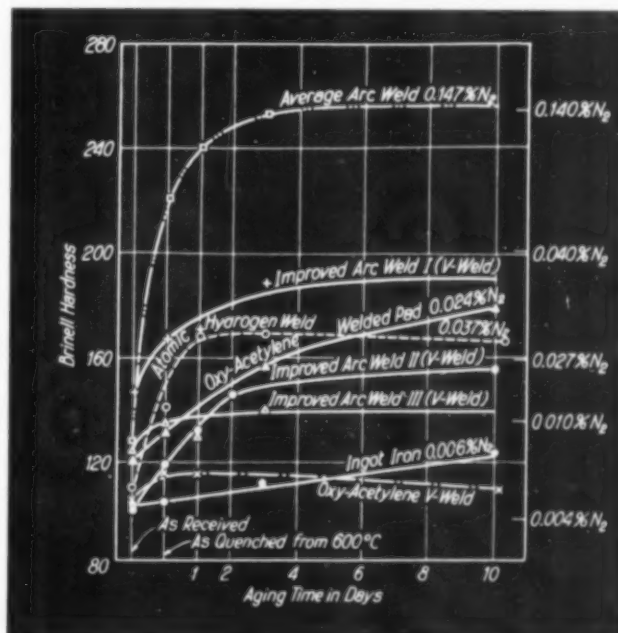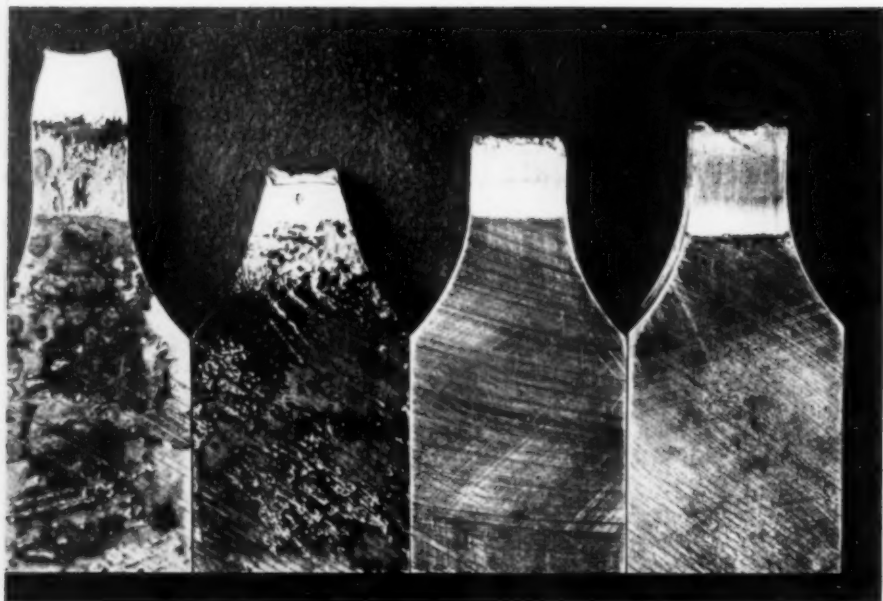
V-Weld in Special Test Piece Breaks if It Is Quickly Tested But if Quenched and Aged Is Stronger Than High Strength Plate

welds made with bare wire all exhibit the same general aging characteristics. Aging of arc welds can be greatly reduced if protective coatings and special techniques are employed. This is evident from the figure at the lower part of page 45. The susceptibility to embrittlement is apparently a function of the nitrogen content of the metal. Therefore the right-hand ordinate shows the amount of nitrogen necessary to produce the hardness values indicated at the left side of the curve.

The increase in nitrogen above a certain percentage apparently does not increase the hardness in the same proportion and arc welds containing between 0.06 and 0.11% nitrogen do not show appreciable differences in their age hardening properties. If, therefore, "improvement" of welds is to be accomplished, the nitrogen content must not exceed the lower limit of 0.06%. Improvement means, in other words, a decrease of the nitrogen content, or more generally speaking, a decrease of the gas content.

The most practicable means of accomplishing that is, according to our present knowledge, the use of coatings and fluxes which fulfill two chief conditions:

(1) Creation of a protective reducing atmosphere with large amounts of free hydrogen present.

(2) Formation of a slag having low melting point, viscosity and density.

Oxy-acetylene welds and atomic hydrogen welds are apparently low enough in nitrogen to make their aging characteristics of minor practical importance.

The difference between weld metal deposited in a V-groove and in form of pads was quite noticeable. Much better properties were obtained with weld metal taken from a V-groove.

In order to prove that the nitrogen is the cause of the age hardening, samples were degasified in hydrogen or in vacuum. After a hydrogen treatment at 1,000° C. for 4 days the weld has lost its age hardening properties nearly completely, and the nitrogen content by Nessler's reagent has dropped to 0.030%.

It might be pointed out here that the nitrogen content alone is not an infallible indicator of susceptibility to aging. The primary requirement for age hardening is a decrease of the solid solubility with temperature of some component of the alloy in question. If the solubility of iron for nitrogen is increased — possibly by adding alloying elements — a decrease in aging effects will result.

Specific Gravity Important

In dealing with tensile properties of arc welded pads we are confronted with the difficulty of obtaining comparable results on account of the inhomogeneity of the material. It was possible to correlate these data by plotting them as a function of the specific gravity, in which case the specific gravity is a measure of the soundness of the material, which was then under investigation.

The elongation values of the quenched and aged specimens decrease to practically zero. The samples in the "as-received" condition show a definite yield point, while none was detected after the heat treatment, the stress-strain curves being characteristic of a brittle material which fails with practically no yielding.

Some of the data obtained on low-carbon steel plates joined with a V-weld in the center are of interest. The degree of embrittlement of the V-type weld cannot be judged by its

elongation because the elongation occurs within the parent metal. This can be clearly seen from the picture opposite. The break occurs in the weld in the as-received sample (right) while in the quenched and aged sample (left) the fracture is in the parent metal. Variation in tensile properties and elongation can be attributed to the age hardening properties of the weld. The heat treatment increases the ultimate strength of the weld without noticeably affecting the properties of the parent metal. The higher stress thus necessary to cause fracture of the specimen causes greater strain in the parent body of metal.

A series of impact tests was run to check the tensile test results. The data are given in the table. Each value is the mean of four to six tests made after each treatment.

Micros Showing Dispersion Hardening of Iron Nitride. All etched with 2% nital and all 500 diameters except first which is 1,000 diameters. Weld as received (bottom) has characteristic nitride plates which disappear after quenching from 600° C. Aging 10 days at 100° C. brings back tiny scattered plates; 70 days at 200° C. restores structure of original metal (top)
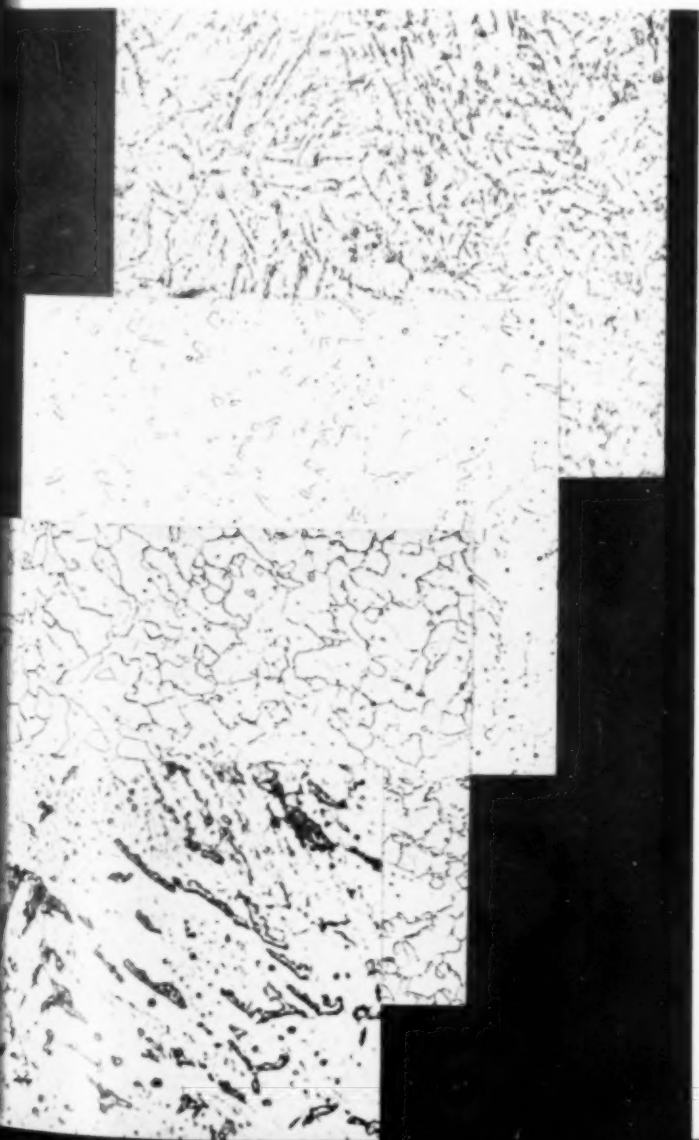
Impact Strength in Foot-Pounds

	As Received	Quenched from 600° C.	Quenched and Aged
Bare arc, pad	2.5	2.0	1.7 (10 days)
Bare arc, V-weld	1.4	5.3	2.6 (2 days)
Oxy-Acetylene, pad	33.8	38.0	8.3 (8 days)
Atomic hydrogen, pad	68.0	70.3	79.0 (8 days)

The results are similar to those revealed by the tensile tests. In a number of cases the impact values increase after quenching, but drop considerably after aging. The velocity of precipitation seems to be slightly different in the various materials. The atomic hydrogen weld exhibited rather high impact values and showed no detrimental aging effects.

Precipitation of iron-nitrogen compounds can be observed by means of the microscope. In the as-received state the arc welds show plates of nitrides arranged in Widmanstätten pattern. The needles are colored brown by etching in 2% nital and darkened after an etch with hot alkaline solution of sodium picrate. After quenching from 600 C. the needles have disappeared. The particles precipitated during aging at room temperature are so highly dispersed that they cannot be seen under the microscope. After aging for 10 days at 100 C. the precipitate formed is of irregular shape with a tendency to form sharp cornered particles. After etching in sodium picrate the particles seem to consist chiefly of elongated plates arranged in a random manner. When aged for 10 days at 200 C. the amount of precipitate increases somewhat and after 70 days at 200 C. the ground mass is covered with the precipitate which again assumes the needle-like structure.

With regard to the nature of the needles, we are quite sure that they are caused by nitrogen. The characteristics of the needles, such as appearance after etching, sensitivity to heat treatments and the darkening by hot sodium picrate, are not characteristic of iron-oxygen compounds. There is, of course, the possibility that a needle-like structure may be caused by a number of other elements, but in the arc welds, nitrogen is undoubtedly the cause.

In conclusion, therefore, arc welds made with bare wire are iron-nitrogen alloys showing pronounced aging effects. To avoid the latter, and insure proper ductility, nitrogen must be 0.05% or lower.

By W. E. Jominy
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Furnace
Scale
on
forging
heats

ONE of the metallurgical factors involved in heating steel for forging is scaling of the steel. It is more or less taken for granted in most forge shops, but is really more of a factor than is usually realized. It is not always appreciated that scaling enters definitely into a number of items of cost other than the mere loss of metal and, further, that scaling is an important cause of a number of undesirable qualities in the finished forging.

Scale ruins many refractories with which it may come in contact in the heating furnace; it results in wrong dimension parts; sometimes it causes sticking in the forging dies; and occasionally it gets pounded into the forging, resulting in weak spots and machining difficulties. Furthermore, most forgings must have the scale removed before being used or machined and, whether by pickling or other means, this is the more expensive the deeper and more adherent the scale.

It is evident that the presence of scale in a finished drop forging adds considerably to its cost and may seriously affect its quality.

A general investigation of the metallurgical principles involved in the application of heat to forging was started at the University of Michigan for the Committee on Industrial Gas Research of the American Gas Association about five years ago. The factors which were considered most important in a study of scaling were the effect of atmospheres or individual gases, the period of exposure, and the protecting action of the first scale formed. Part of the

results of the investigation of this subject have been already published by the authors in a paper read before the 1930 Chicago Convention (*Transactions*, A.S.S.T., Vol. 18, p. 19) which deals with the effect of temperature, pressure, rate of flow, and period of exposure on the scaling of steel in the pure gases which may be found in the atmosphere of a gas-fired furnace.

The present paper, in which the same methods of attack were used, deals with the effect on scaling of steels of the composite atmospheres which may be found in a gas-fired furnace, whether the furnace is fired with excess air, excess gas, or the correct amount of both.

In the tests we burned a commercial gas with a definite amount of air and permitted the products of combustion to pass over a steel sample at a controlled temperature and for 40 min. At the end of this time the sample was quenched in distilled water, and the scale removed by electrolytic pickling. (This and other methods are described in detail in the paper previously cited.) Loss of weight due to scaling was easily obtained and by comparing this value with the weight of the scale, the percentage of iron in the scale could be computed.

The furnace was a gas-fired carborundum muffle through which passed a porcelain tube stoppered at each end for entrance and exit

Scaling of S.A.E. 1015 Steel Exposed 40 Min. At the Temperatures Shown To Atmospheres Formed By Burning Gas and Air In Various Proportions

of sample and gases. Small pieces of porcelain filled this tube ahead of the gas-air delivery tubes for a space of about 9 in. in order that the air-gas mixture would be thoroughly burned and mixed before coming in contact with the steel sample.

City Gas Used

Gas was a 530-B.t.u. mixed coke oven and carburetted water gas. In order to have gas of identical analysis for a given series of tests, a large tank was filled from the city gas line by a compressor at 125 lb. per sq.in., thus storing approximately 62 cu.ft. of gas (measured under standard conditions). A representative analysis is 4% CO_2, 8% unsaturated hydrocarbons, 2% O_2, 20% CO, 45% H_2, 13% CH_4, and 9% N_2. The gas in this tank was analyzed before mixing with air at the furnace.

Products of combustion of the air-gas mixture, which burned as it was introduced into the end of the furnace tube, were also analyzed.

Suitable flow meters regulated the quantity of air and gas passed into the tube, kept them at a predetermined ratio, and established a rate of flow of the products of combustion at about 60 ft. per min.

Steel test samples were all of cylindrical shape, about $\frac{3}{4}$ in. round and 2 in. long, polished bright.

A first series of tests was made at 2,300° F. with the S.A.E. 1015 steel (carbon 0.19%) used in previous work. Atmospheres were produced by burning gas with air in the ratio of 1 air to 1 gas, 2 to 1, $2\frac{1}{2}$ to 1, 3 to 1, $3\frac{1}{2}$ to 1, 4 to 1, $4\frac{1}{4}$ to 1, $4\frac{1}{2}$ to 1, $4\frac{3}{4}$ to 1, 5 to 1, $5\frac{1}{2}$ to 1, and 6 to 1. Mixtures having $4\frac{3}{4}$ air to 1 gas (of the composition used in these tests) after combustion contain practically no free oxygen, hydrogen, or carbon monoxide. When less air than $4\frac{3}{4}$ air to 1 gas is used there is some carbon monoxide and hydrogen but no free oxygen. When more air is used — as with mixtures of 5 air to 1 gas — no carbon monoxide or hydrogen is present but there is some free oxygen.

Results of these tests are plotted in the first figure, and locate the curve marked 2,300° F. In this figure the loss in weight of the steel sample is measured in pounds per 100
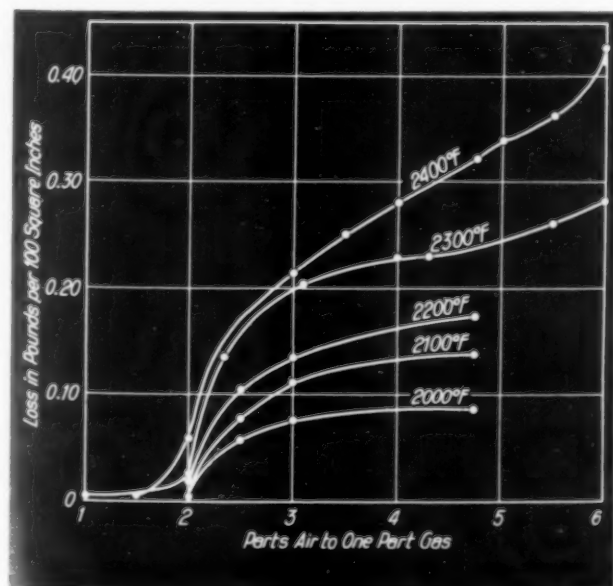
Ratio Air÷Gas	CO Observed	Actual Gas Atmosphere					Weight Loss	Scale Formed
		CO_2	CO	H_2	H_2O	N_2		
4.61	0	12.0	0	0	17.9	70.1	0.237	0.298
4.69	2.1	10.8	1.7	1.2	17.8	68.5	0.233	0.296
4.17	4.3	9.8	3.5	2.6	17.6	66.5	0.232	0.294
3.88	5.9	9.3	5.0	3.8	16.2	65.7	0.227	0.290
3.55	8.0	8.3	6.8	5.6	15.7	63.6	0.214	0.271
3.18	10.4	7.2	8.8	8.2	14.8	61.0	0.182	0.242
2.86	12.1	6.0	10.4	10.3	14.7	58.6	0.156	0.198
2.33	15.0	4.6	13.1	15.1	12.8	54.4	0.016	0.021
1.17	16.4	2.9	14.6	22.8	10.9	48.8	0.004	0.004

sq.in. surface and plotted against air-gas ratio.

It will be observed from this curve that there is little change in the amount of scale produced as the air is reduced in the air-gas mixture from 4¾ parts to 4 parts air. Since 4¾ air to 1 gas corresponds to the "neutral point," these data indicate that practically no decrease in the rate of scaling results when the combustion furnace is fired with a slight excess of gas, such as would produce about 1% carbon monoxide, as compared to the rate of scaling with a correct combustion mixture when there is no carbon monoxide or free oxygen.

Further, the rate of scaling decreases rather gradually as the air is reduced from 4 parts air to 1 part gas to 2½ parts air, then falls off very sharply, and approaches zero at 2 parts air to 1 of gas. When, however, there is a slight excess of air, as with 5 air to 1 gas, or more especially with 5½ parts air (which would correspond to about 2% free oxygen) there is a very definite increase in the rate of scaling.

Tests in similar atmospheres were made at 2,000° F., 2,100, 2,200, and 2,400° F. and the results also plotted in the first figure. It will be noted that these curves are quite similar in shape. Therefore, what has been said about the tests at 2,300° F. applies fairly well at these other temperatures. It is plainly shown that increase in temperature causes an increase in the rate of scaling.

Another series of tests included a number of plain carbon steels, S.A.E. 1030 (Si less than 0.01%), 1050, 1090, and a tool steel containing 1.12% carbon. In these tests the air-gas mixtures were adjusted for definite CO content in the products of combustion. Tests were first made in so-called neutral atmospheres, that is, in atmospheres in which the percentage of carbon monoxide or free oxygen was not over 0.2%, and then in atmospheres containing about 2% carbon monoxide, then 4, 6, 8, 10, 12, 15, and 16.5% carbon monoxide respectively.

A summary of results of these tests on S.A.E. 1015 steel is presented in the table, where each line represents the average of two or more runs. The figure listed in this table under the column marked "CO Observed" is the ordinary gas analysis made on a dry basis which is obtained with an ordinary Orsat apparatus. The complete gas analysis presented in the table gives the true composition of the atmosphere in which the sample is immersed. "Weight Loss" and "Scale Formed" are computed on the basis of pounds per 100 sq.in. of exposed steel.

Examine the composition of the gas atmosphere in this table and note the importance of steam as well as carbon dioxide in producing scaling, and conversely the importance of hydrogen as well as carbon monoxide in preventing scaling. For those tests shown on the next to last line, in which only a very small amount of scale was formed, the

Scaling of Various Carbon Steels at 2,300° F. During 40 Min. In Various Furnace Atmospheres As Shown By Loss in Weight of the De-Scaled Steel
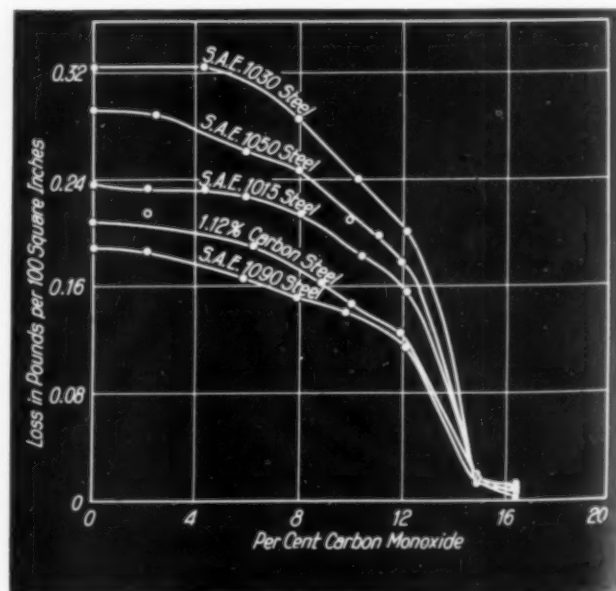
ratio of carbon monoxide to carbon dioxide is 2.85 to 1 and the ratio of hydrogen to moisture is 1.18 to 1. Apparently, these ratios must be slightly increased to eliminate all scaling. An investigation of this point has just been completed and it has been found that at 2,300° F. the ratio of hydrogen to moisture which will just prevent scaling is 1.3 to 1. The ratio of carbon dioxide to carbon monoxide that will just prevent scaling is a problem which is also being investigated.

Data in this table are presented in the figure on page 50 on the curve labeled S.A.E. 1015 steel, in which the loss in weight in pounds per 100 sq.in. is plotted against the observed per cent of carbon monoxide. It will be observed from the shape of this curve that there is only slight change in the rate of scaling as the carbon monoxide increases from 0 to 6%. From this point to 12% carbon monoxide the rate of scaling decreases rather uniformly; between 12% and 15% the rate of scaling decreases very sharply and approaches zero at 16.5% CO.

Results of the tests on other plain carbon steels are plotted in the same figure. The tables of data presenting the observed and calculated gas analysis of the atmospheres used in the tests as well as the quantity of scale produced have been omitted to conserve space. The tests were made at 2,300° F. and for a period of 40 min.

These curves are quite similar in general characteristics to that for the S.A.E. 1015 steel, although the rate of scaling of each individual steel is different. The two high carbon steels seem to scale a little less than the low carbon steel under like conditions and considerably less than the medium carbon steels. The scale removed from the high carbon steels was in finer flakes than that from the other steels. The chemical composition of the scale, however, was found to be practically the same, all of it corresponding to the formula FeO.

In view of the relative rates of scaling which are shown by these tests, it cannot be concluded that the rate of scaling is directly proportional to the carbon content. It is true that the high carbon steels seem to have scaled more slowly than the others but it is equally true that the low carbon steel scaled more slowly than the medium carbon steels.

It seems quite evident that the action of

Experiments on Carbon Steels at 2,300° F., Re-Plotted To Show Amount of Scale Produced in Various Furnace Atmospheres

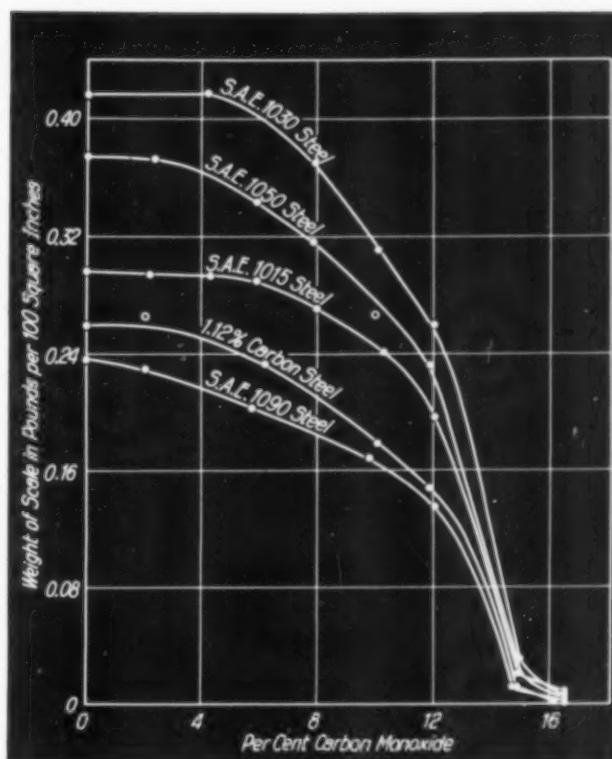the various furnace gas atmospheres is quite regular. There is very little difference in the scaling action of an atmosphere containing no carbon monoxide (and no oxygen) and an atmosphere containing 6% carbon monoxide. From 6 to 12% CO there is a gradual falling off in rate of scaling and scaling decreases very sharply from 12 to 15% CO. At 16.5% CO there is practically no scale produced. It is, of course, understood that these atmospheres are made by burning gas with insufficient air (except where the analysis shows no carbon monoxide), and that in addition to the carbon monoxide there is hydrogen, carbon dioxide, and steam. The approximate proportion of these latter gases may be obtained by reference to the table which gives these percentages for the tests on the S.A.E. 1015 steel.

The results presented in the previous figures were obtained from weighing the steel before and after heating. A factor which also affects the loss in weight is the decarburization of the unscaled portion of these steels, due to the action of these same atmospheres. This loss in carbon is a relatively small error, but is
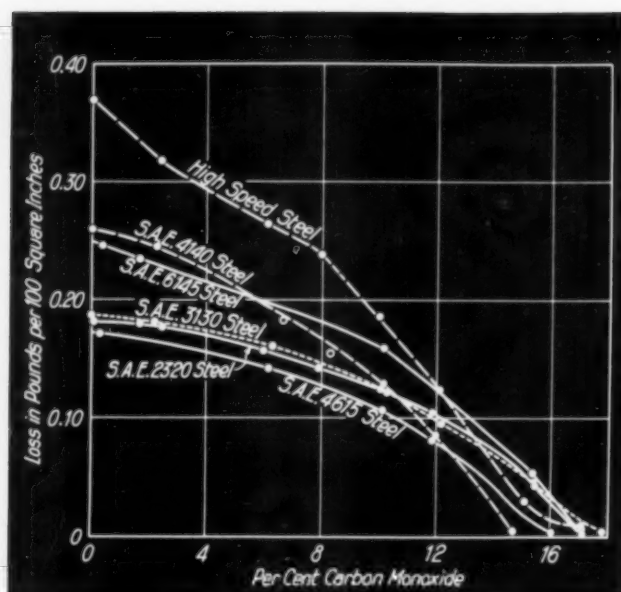
*Scaling of Alloy Steels at Forging Heats Is On
Same Order as That of Plain Carbon Steels*

variable since it will be greater with high carbon steels and almost negligible with the low carbon steel. Since the scale was collected and weighed, its amount will eliminate the error from decarburization. Hence the third set of curves was plotted, which gives the weight of the scale. It will be seen that the curves have the same general characteristics as in the second figure, although the ordinates are higher since they correspond to weight of the scale removed (iron plus oxygen).

In order to determine whether some of the common alloy steels behaved like the plain carbon steels, tests were made on a high speed steel containing 18.6% W, 4.3% Cr, and 1% V, an S.A.E. 4140 chromium-molybdenum steel, an S.A.E. 6145 chromium-vanadium steel, an S.A.E. 3130 nickel-chromium steel, an S.A.E. 2320 nickel steel, and an S.A.E. 4615 nickel-molybdenum steel. These steels were also tested at 2,300° F. for 10 min. in atmospheres produced by burning gas with various amounts of air. The results of these tests are plotted in the above figure, in which the loss in weight in pounds per 100 sq.in. of surface is plotted against the per cent of carbon monoxide in the atmosphere. The carbon monoxide percentages used here, as in the other curves, are those determined by the gas analysis (not the actual amount computed to include the steam) and are therefore

comparable to those obtained when analyzing a furnace atmosphere with the ordinary Orsat equipment which dries gas before measuring.

It will be seen by examining these curves that the rate of scaling of the alloy steels is of the same order as the plain carbon steels. The general characteristics of the curves are quite similar to those for the plain carbon steels between 0 and 12% carbon monoxide. Above this percentage the curves are somewhat different, although the rate of scaling approaches zero at 16.5% CO as before.

High speed steel scaled more than the others in the atmosphere containing less than 12% carbon monoxide. The type of scale formed appeared to be quite different from any other; it was irregular in size of flake and the flakes were large, porous, and lumpy. The scale was also much more difficult to strip. High speed steel was the only one in which the rate of scaling was appreciably higher in a so-called neutral atmosphere than in one with 2% CO.

The chromium-molybdenum steel, S.A.E. 4140, and the chromium-vanadium steel, S.A.E.

6115, showed about the same rate of scaling in atmospheres containing less than 10% carbon monoxide. The nickel-chromium steel, S.A.E. 3130, the nickel steel, S.A.E. 2320, and the nickel-molybdenum steel, S.A.E. 4615, all scaled at about the same rate, lower than the former two.

An analysis of the nickel in the scale from the 2320 nickel steel showed it to contain 0.23%, whereas the nickel in the steel was 2.40%. Evidently the nickel in the steel is not oxidizing as fast as the iron, and there should consequently be an increased amount of nickel content on the surface of this steel. To determine whether this was likewise true of the chromium in the nickel-chromium steel, an analysis was made, but the scale was found to contain 0.49% chromium, which is not much less than the 0.56% in the steel.

The ratio of the loss in weight of the test samples to the weight of scale removed in all of the alloy steels studied (with the exception of the high speed steel) was about 0.78 to 1. With high speed steel there was considerable variation in the ratios, partially due to decarburization. With all the other alloy steels this constant ratio would indicate that the scale was very nearly all ferrous oxide, FeO.

Large Gas Excess Unnecessary

The application of these results to commercial practice is now considered, since this research had as its objective to find ideal conditions for heating steel for forging, in order that better furnaces might be designed by agencies of the American Gas Association. It has been shown that if a gas-fired furnace is heated with a mixture containing more air than required for the combustion of the gas, the products of combustion of such a mixture will scale steel at a faster rate than when no excess air is used. Further, it has been found that to reduce scaling below the rate that occurs in a so-called neutral atmosphere, a large excess of gas over air is required. A small excess of gas, such as would produce an atmosphere containing about 6% carbon monoxide, will not reduce the scaling appreciably below that obtained with a correct mixture of air to burn the gas completely. It would therefore seem wiser to main-
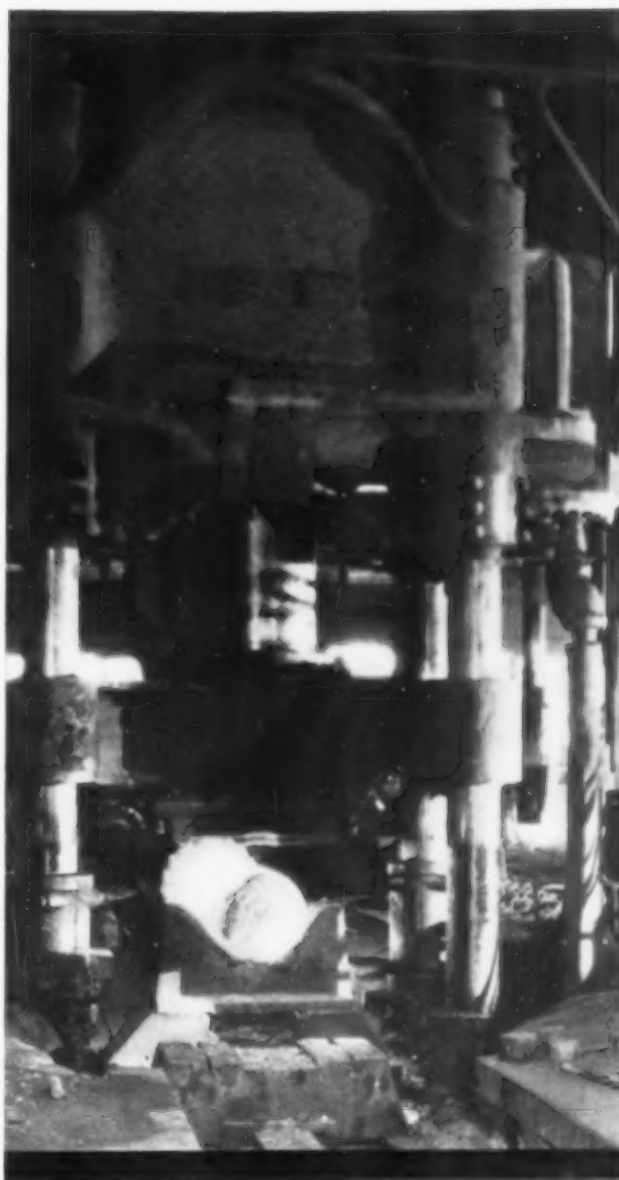
Courtesy Allis-Chalmers Mfg. Co.

tain a mixture as nearly correct for the complete burning of the gas as possible and thus obtain the greatest economy of operation. It must, of course, be borne in mind that any excess of air should be carefully avoided and it would therefore be advisable to try to maintain a furnace atmosphere between 0 and 0.5% CO.

To obtain a decided reduction in the rate of scaling it is necessary to burn with sufficient excess gas to produce an atmosphere containing about 14% carbon monoxide, and to eliminate scaling at least 16.5% is necessary.

These recommendations can only be safely applied at forging temperatures above 2,000° F. and to furnaces using manufactured gas.
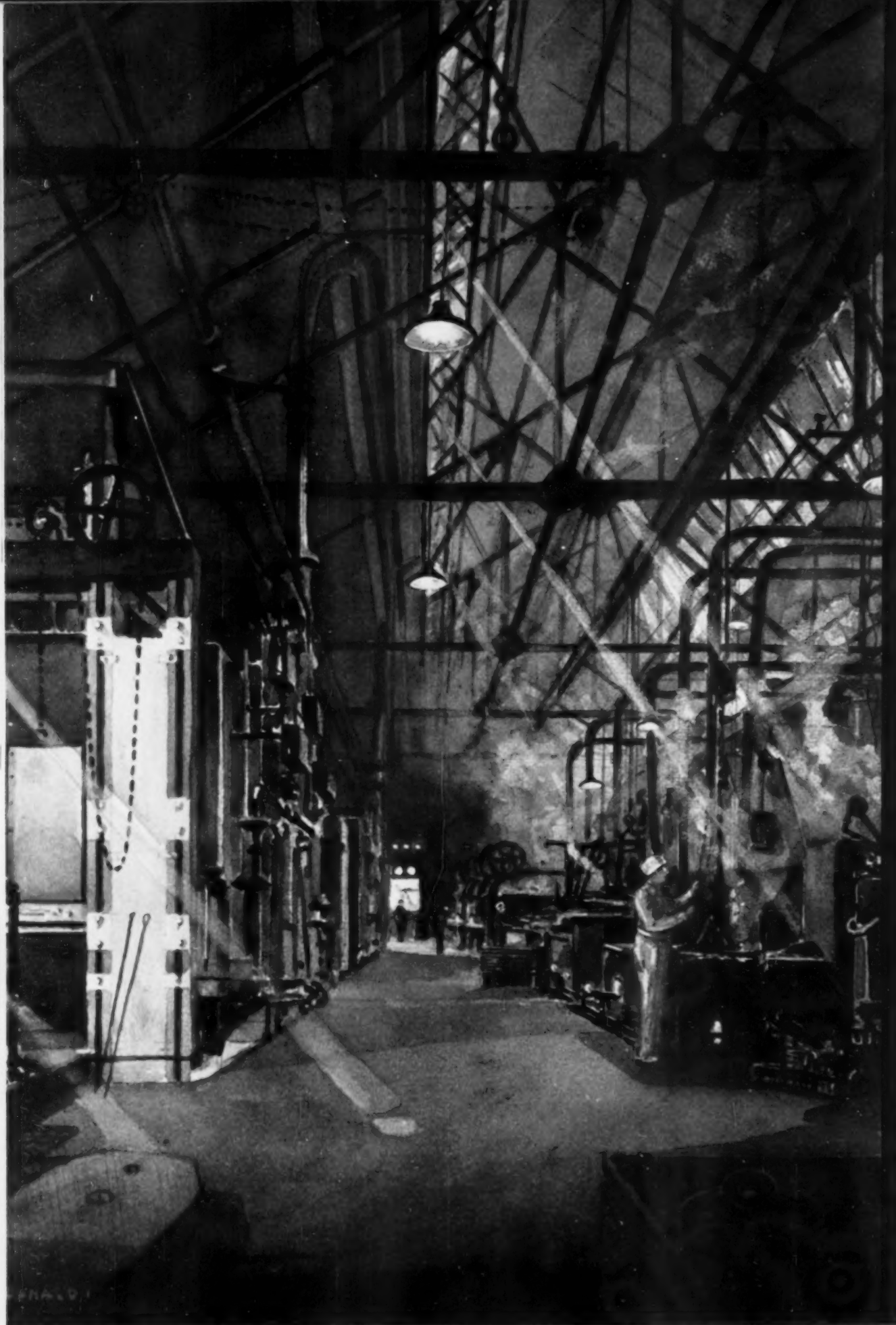
From a Watercolor by Edward D. McDonald

Courtesy Eaton Axle & Spring Co.

Science Has Replaced Tradition

Quenches

intermediate

between

oil and water

By T. E. Hamill
Bureau of Standards
Washington

STRUCTURE and the properties of a quenched steel depend upon both the critical cooling rate of the particular steel in question and the cooling characteristics of the medium in which the steel is quenched. The simplest and most widely used quenching media are water and oil. The cooling characteristics of these two have been modified by adding salts, alkalis, acids, or other chemical compounds to water, by using water or aqueous solutions at temperatures below or above room temperature, and by employing emulsions of oil and water.

If quenching solutions were available which give a completely graded series of cooling rates, the control of the results to be obtained from quenching both plain carbon and alloy steels would obviously be much more simple. Oil-water emulsions, concentrated sulphuric acid, and hot aqueous solutions have been used in the attempt to supply this need.

Experiments previously made at the Bureau of Standards on emulsions of water and machine oil showed that the addition to water of only 0.1% of oil, by volume, decreased the cooling rate of the water almost to that of the oil alone. The extreme accuracy that apparently is required in preparing and maintaining emulsions of this type in order to secure quenching solutions of a known cooling rate appears to limit seriously the usefulness of such emulsions.

Concentrated sulphuric acid will give cooling rates between those obtained with oil and water. Its disadvantages are its hygroscopic nature (making maintenance of its concentration difficult) and the very great danger to workmen from splashing.

Hot water and hot aqueous solutions are sometimes used to give cooling rates intermediate between those of oil and water. Such solutions require good circulation and accurate control of temperature and concentration. Solutions of glycerine also have been used as quenching media. The present investigation was directed chiefly toward a study of solutions of sodium silicate as quenching media, which it was expected might give cooling rates intermediate between those of oil and of water.

Cooling curves of the surface and the center of steel cylinders $\frac{1}{2}$ in. diameter by 2 in. long, were drawn during a quench from 875° C. (1,600° F.) in several coolants at various temperatures from 20 to 80° C. (68 to 176° F.). The quenching media were moving with a velocity of 3 ft. per sec. The time-temperature curves were obtained on a moving photographic film by an Einthoven "string galvanometer."

Hardness was determined at the surface and at the center of the specimen. A study was also made of the hardness and microstructure developed in cylindrical "stepped" bars which

were machined to have abrupt changes in diameter from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. to 1 in.

Hardness tests were made after wet grinding 0.01 in. deep; results are averages of six. The metal used was 1% plain carbon steel.

Commercial sodium silicate from two sources was used in the preparation of the silicate quenching solutions. One contained approximately 6% Na_2O, 25% SiO_2 by weight, and the other approximately 11% Na_2O, 27% SiO_2 (the balance being water). Ratios of soda to silica were thus nearly 1:4 and 1:$2\frac{1}{2}$. Various solutions of these silicates were used as quenches, ranging from 4.6 to 41.8° Bé.

Surface and center cooling curves obtained during quenching the standard sample in various concentrations of the 1:4 sodium silicates at 20° C. are shown in the first figure. Cooling curves obtained during a quench in water and in oil at 20° C. are also given for comparison.

Increasing the concentration of solutions lowered the cooling rates. Cooling times increased from slightly less than that of water to greater than that of oil. The surface cooling in the 23.2° Bé. solution is much slower than in the oil, while the center cooling was about the same for both quenching media.

Experiments such as these discovered five

Cooling of the Surface and (Below) Center of $\frac{1}{2}$-In. Steel Rounds Quenched in Sodium Silicate Solutions. Cooling rates which are intermediate between oil and water are thus secured

solutions with cooling rates intermediate between water and oil — namely, 9.5°, 13.2°, and 16.7° Bé. solutions of the 1:4 silicate, and 12.4° and 28.8° Bé. solutions of the 1:$2\frac{1}{2}$ silicate.

Decrease in center cooling rate and increase in surface and center cooling times with increasing concentrations of the sodium silicate solutions are better shown in the second set of curves. The relation between the center cooling rate and the concentration of the 1:4 sodium silicate is almost linear up to concentrations of approximately 20° Bé. At higher concentrations the cooling rate changes relatively little with increasing concentration. On the other hand, with solutions of the 1:$2\frac{1}{2}$ silicate, the center cooling rate, the surface cooling time and the center cooling time are very little affected by increasing the concentration up to approximately 28° Bé. Higher concentrations, however, produced rapid changes in both the center cooling rates and surface and center cooling times.

Center and surface hardnesses are also shown in the same figure. The steel was fully hardened at the center (Rockwell C65) on quenching in the 4.6 and 9.5° Bé. solutions of the 1:4 sodium silicate. Steel quenched in these two solutions was almost completely martensitic in structure with small amounts of troostite. With increasing concentrations of the 1:4 silicate there was an abrupt decrease in center hardness and in surface hardness at concentrations of 9.5° Bé. and 13.2° Bé., respectively. Increasing amounts of troostite and finally sorbite and pearlite correspond with these changes in hardness.

The center cooling rate at 720° C. corresponding to the highest concentration of the 1:4 silicate giving practically complete center hardening, was 115° C. per sec. The center cooling rates in solutions of the 1:$2\frac{1}{2}$ sodium silicate exceeded this critical rate in all concentrations up to approximately a 31° Bé. solution. Consistent with this are the center hardness values which show complete hardening on quenching in 28.8° Bé. solution of the 1:$2\frac{1}{2}$ silicate.

It appears possible that the relatively slow cooling rates obtained with sodium silicate solutions may be due to deposits of silica which form on steel quenched in such solutions. While no definite measurements were taken, it was
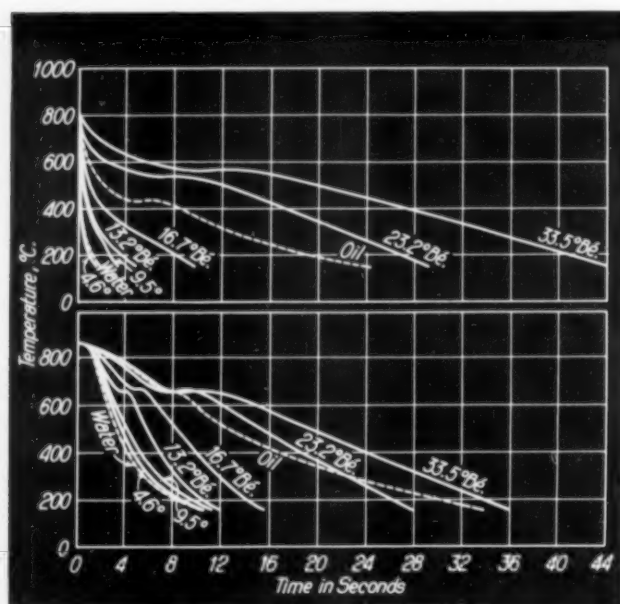
observed that cylinders quenched in low concentrations of sodium silicate had a much thinner layer of silica than those quenched into highly concentrated solutions. Photographs of quenched "stepped" bars verify this observation.

Increasing the temperature of the sodium silicate solutions from 20° to 80° C. decreased the center cooling times in all concentrations investigated; the change is smaller, however, between 20° and 50° C. than between 50° and 80° C. This behavior is a distinct advantage, since it indicates that the quench can warm somewhat without making large changes in the properties of the quenched steel. When using solutions of low concentration the variation in the temperature of the medium must be kept to a minimum if no variation in the quenched sample is to be expected. When using higher concentrations the cooling rate is much less affected by changes in temperature.

While considerable importance has been attached to the center cooling rate at 720° C., it is realized that structure and hardness of a quenched specimen depend on other factors, such as the cooling times from quenching temperature down to 100° C., and the cooling rates at the Ar″ point. However, the cooling rate just preceding the Ar′ point determines whether austenite will change into martensite, into troostite, sorbite or pearlite. If the center cooling rate does not exceed the "critical cooling rate" of the steel, a combination of two or more of the above structures will appear. If it is exceeded, the austenite remains stable until the Ar″ transformation is reached, where all or part is transformed into martensite, depending then upon the cooling rate at the lowered transformation. When this change into martensite occurs, it will be accompanied by an increase in volume which sets up internal stresses if the change does not occur throughout the entire specimen.

It was expected that some of the stepped bars, with their sharp corners and large variations in size, would crack when quenched in some of the cooling media used. Such cracking frequently occurs on rapid cooling, caused by the high internal stresses set up as a result of the volume changes which accompany the structural changes during the hardening of steel.

The material from which the stepped bars
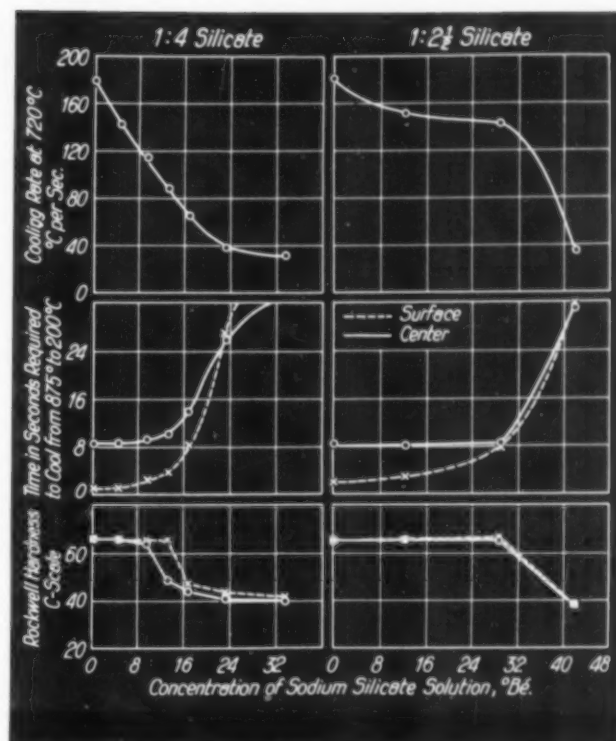
Correlation Between the Rates of Cooling, the Time Required for Cooling and the Hardness of a Series of Specimens Quenched in a Number of Sodium Silicate Solutions

were machined was first given a preliminary heat treatment by heating to 850° C. (1,560° F.), holding for one hour, and cooling in air. They were then annealed at 760° C. (1,400° F.) for one hour and cooled in the furnace.

It was rather surprising that none of the bars cracked immediately on quenching. However, the specimens for hardness tests and microscopic examination which were cut from the bars quenched in the two fastest quenching media (water and the 4.6° Bé. solution), did crack later.

The tendency of these bars to distort and crack could no doubt have been somewhat reduced if the bars had been moved rapidly up and down in a vertical position during the quenching instead of keeping the bar still while the quenching medium was flowing past the bar (the standard procedure for the purposes of this investigation).

The $1\frac{1}{4}$-in. sections of the bars that had been quenched in water and in the 4.6° Bé. sodium silicate solution were the only sections that hardened completely throughout; that is, whose structure was martensite free from troostite.

These samples had a center hardness of 66 on the Rockwell C scale.

It is evident from the hardness tests and their corresponding microstructures that samples having a martensitic structure with some primary troostite had practically the same hardness as those samples having a martensitic structure free from primary troostite. It may be concluded, therefore, that hardness tests alone cannot be used as a means of determining whether the steel is completely martensitic in microstructure.

Sodium silicate solutions, like nearly all quenching solutions, have advantages and disadvantages. Among their advantages are their low cost and the fact that they do not readily corrode the steel.

The chief disadvantages of sodium silicate solutions as quenching media are the formation of a thin coating of silica on the surface of the quenched piece and the instability of some of the solutions. The thin coating of silica that forms when using high concentrations of sodium silicate can be removed slowly by dissolving it in water or by boiling in a dilute sodium hydroxide solution. After most treatments it should not be necessary to remove this coating.

Some trouble was experienced with the instability of certain of the solutions of the 1:4 sodium silicate. A flocculent precipitate formed in the 9.5°, 13.2°, and 16.7° Bé. solutions on standing from six weeks to two months. However, solutions of these same concentrations made up with the addition of 2% of sodium hydroxide of specific gravity of 1.065 at 20° C. showed no evidence of instability and breaking down after three months. The addition of sodium hydroxide was without effect on the cooling rates of these solutions. Sodium silicate solutions of 4.6° and 23.2° Bé. remained stable for more than three months, even without additions of sodium hydroxide. The stability of solutions of the 1:2½ sodium silicate was not investigated. Presumably, these solutions would be more stable than solutions of the 1:4 sodium silicate on account of the higher soda content.

Specimens Which Have Been Quenched in Sodium Silicate Solutions Acquire a Deposit of Salt Whose Thickness Varies Approximately With the Specific Gravity of the Solution. This may be a determining cause of the respective quenching rates

°Bé.   9.5°Bé.   13.2°Bé.   16.7°Bé.   23.2°Bé.   Oil   Water
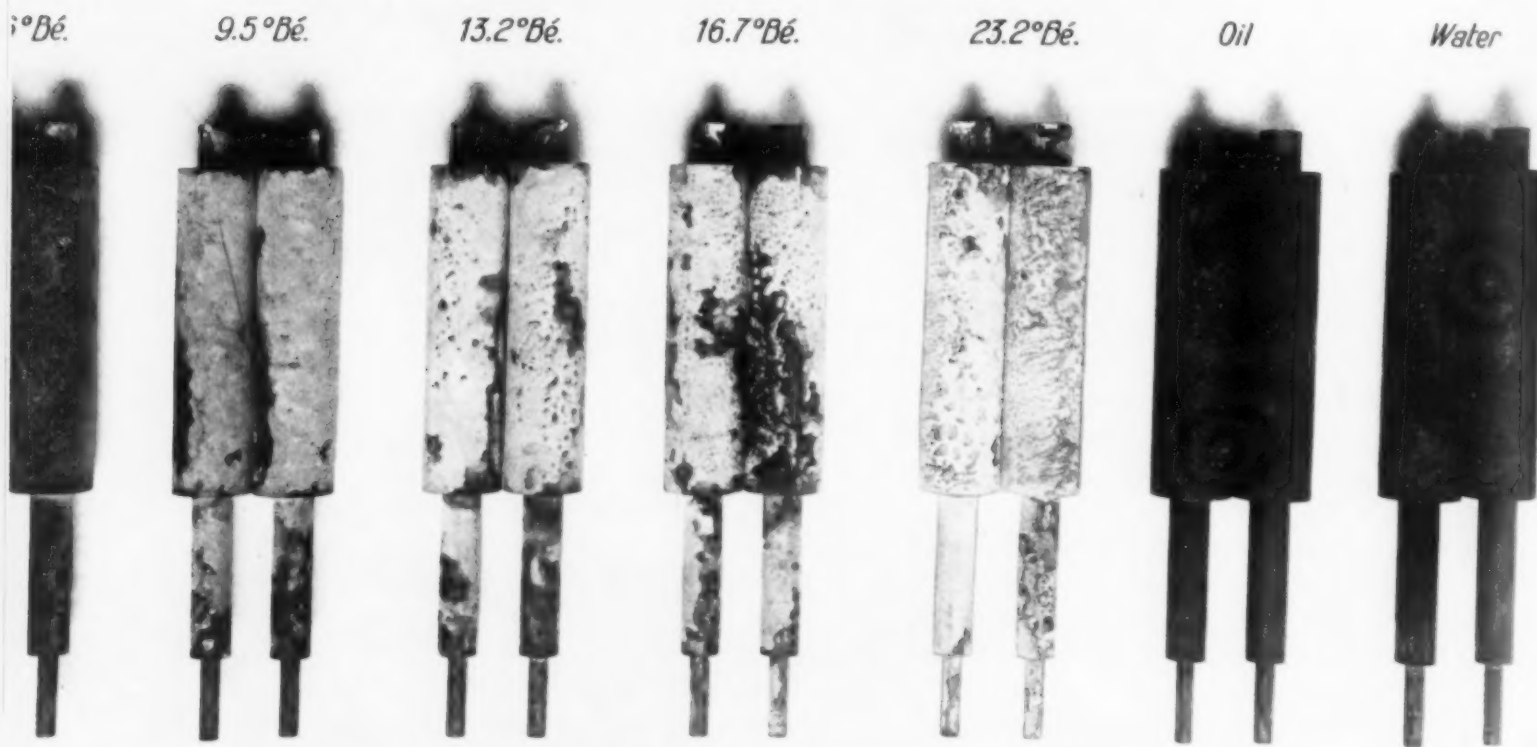
By E. W. Ehn
SKF Companies
Cannstatt, Germany

Seasoning

of Steel

effect of
carbon
nitrogen
copper
in small amounts

IN A LETTER, published in METAL PROG-
RESS in May, under the heading of "For-
eign Letters," the general theory advanced by
Dr. Masing, to explain the age hardening or the
precipitation hardening of steel, was outlined.
The specific influence of the alloying elements
which most frequently cause this hardening
action will now be described more in detail.
Carbon will be considered first. Nitrogen and
copper will then be discussed.

It may be advisable to repeat that the car-
bon which participates in the usual hardening
operation of a medium and high carbon steel
has no later influence in age hardening. The
active part of the carbon subsequently causing
this precipitation hardness is that minute quan-
tity of carbon that is soluble in alpha iron at
temperatures under the critical point.

It is also desirable at the outset to distin-
guish sharply between two meanings of the term
"aging." The one which will be discussed here
is most easily developed in low carbon sheet,
wire and weld metal, is entirely similar to the
hardening of alloys of the duralumin type. It
has been suggested that "seasoning" would be
a good term for the phenomenon. The other
type of aging was mentioned by Dr. Giolitti in
his letter in the July issue, page 87, and is
especially noticeable in mild or medium steels
showing originally a high impact value. If these
steels are deformed by cold work the elastic
limit and tensile strength are increased, but
with the lapse of time, at normal or moderately
elevated temperatures, the impact strength grad-
ually decreases. No such clear reason for this
phenomenon is available.

The usual iron-carbon diagram is well
known to every metallurgist. There is, how-
ever, one portion of the field that until recently
has been comparatively overlooked. This is the
lower left-hand corner of the diagram, repre-
senting the condition of low carbon steels at

moderately elevated temperatures. The appearance of this part of the diagram is shown in the sketch on page 61.

This is a typical diagram for an alloy system wherein precipitation hardening is possible. The solubility of carbon in alpha iron at room temperature is shown to be slightly below 0.01% and at a temperature immediately under the Ae line it is about 0.04%. If a piece of steel is heated to a temperature of 650 to 700° C., about 0.03% of carbon will therefore go into solution in the alpha iron below the transformation. If the steel is now cooled from this temperature slowly, this absorbed carbon will be precipitated from the alpha-iron solid solution as the temperature decreases, and the resulting carbide

to 400° C. and aging, but this effect is rapidly increased after quenching from temperatures up to 700° C. The speed of quench, where carbon is to be the active element, must be rather rapid in order to obtain maximum amount of the unstable solution. In thin sections an air cooling, or a cooling rate such as obtained in hot rolling of wire or sheets, is quite fast enough to be followed by considerable changes in the physical properties.

It must also be remembered that in practice the changes under discussion are caused not only by carbon but also by other elements present, such as nitrogen and copper, and especially with the latter the rate of cooling from the last heat is of lesser influence.

Steel No.	Chemical Analysis				Original Hardness	Brinell Hardness After Aging					
	Carbon	Silicon	Manganese	Phosphorus		1 Day	2 Days	3 Days	5 Days	7 Days	9 Days
I	0.044	0.0046	0.44	0.036	128	147	172	175	175	185	197
II	0.028	0.0028	0.39	0.029	102	115	136	154	160	168	191
III	0.12	0.0064	0.44	0.043	116	125	143	154	160	170	178

will have time to migrate to the alpha grain boundaries. However, if the cooling speed is rapid, the carbon has not the time and opportunity to rearrange its position and it remains in the solid solution.

This solution is not a stable condition and the carbon is later gradually precipitated at an infinite number of centers within the matrix of the alpha-iron crystals. These precipitation products form the keys that prevent movement along the slip planes of the crystals, thus causing an increase in hardness of the metal. Precipitation will take place slowly at room temperature, but can be speeded up by tempering at 50° to 100° C. If the tempering temperature is raised higher, the precipitated carbon will migrate to the grain boundaries and its influence on this secondary hardness is lost.

It is evident from the preceding explanation that the maximum increase in hardness during aging will be obtained when the low carbon steel is water quenched from a temperature in the neighborhood of the Ae line; either slightly above or slightly below will make little difference in the results.

A perceptible hardness increase has been found after quenching from temperatures of 300

Maximum increase in hardness is obtained by aging at room temperatures for several days. At temperatures of 50 to 100° C., 30 min. to 1 hr. will suffice to give the maximum hardness obtainable at these temperatures. At a tempering temperature of 200 to 250° C. no increase in hardness will be observed above its initial hardness. (This rule, however, is only applicable to the influence of carbon. Other elements show quite different effects.)

Six Points Carbon Very Effective

Age hardening also depends to some extent on the total amount of carbon in the steel; it increases rapidly up to about 0.06%. In steels with higher carbons the hardness after quenching will increase to a lesser extent.

Results of a large number of carefully conducted tests on this phenomenon are now available in the literature. For the purpose of demonstrating the influence of carbon on hardness the information in the above table will suffice.

Other physical properties are correspondingly changed. In samples of a low carbon open-hearth steel, quenched from 660° C., the

Brinell hardness was 119, the tensile strength 57,000 lb. per sq.in. and the elongation 25%. After quenched samples had been aged the respective figures were 172, 78,000 and 13%. These values were approximated by quenching the same steel from 700° C., and then aging, showing that small variations in quenching temperature, near the Ae point, have little effect on the age hardening phenomenon.

As a summary, the following values may be given as typical of the influence of carbon in regard to precipitation hardness by a steel with about 0.10% carbon quenched in water from a temperature immediately under the Ac_1 and aged at room temperature:

Proportional limit ....60% increase
Tensile strength ....up to 55% increase
Hardness ....65% increase
Elongation ....50% decrease
Reduction of area............10% decrease

Practically no change has been observed by bending tests or Erichsen tests, or in the specific gravity, electrical properties, or solubility in etching acids.

Influence of Nitrogen

The iron-nitrogen diagram (page 62) has an obvious similarity to the iron-carbon diagram.

Attention was called to the fact that the hardening effect obtained with carbon by means of the regular quench and draw has nothing to do with the phenomenon here under discussion. It may also be advisable to call attention to the fact that the precipitation hardening effect from nitrogen is one entirely separate and independent of the hardening action obtained by the nitriding process so favored in America. The latter is a surface hardening effect obtained through the formation of stable nitrides with a high content of nitrogen (Fe_4N with 5.9% and Fe_2N with 11.1% N). These are not dissolved by a heat treatment and their action is therefore entirely different from the action of carbon, both in regard to precipitation hardening and also to the conventional methods used in hardening steel.

Residual quantities of nitrogen in the steel are also an active element in precipitation hardening. The solubility of nitrogen in alpha iron, according to the latest investigations, is only about 0.01% at room temperature and about
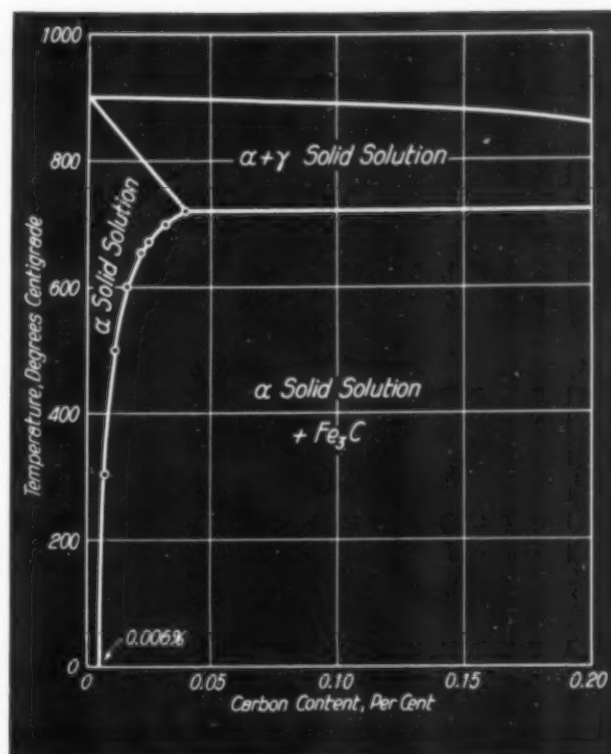
Even Low Carbon Steel May Be Hardened Materially Since Alpha Iron Is Able to Hold Considerable Carbon in Solution at the Transformation, and Most of it May Be Precipitated at Lower Temperatures

0.5% at 580° C. Therefore, two typical conditions to promote precipitation hardening are present. The third condition (that the precipitation product is of such a nature as to be able to block effectively the slip planes in the crystals) is also fulfilled. When the steel is cooled from an initially high temperature, nitrides are precipitated in the form of thin plates that appear on a properly etched surface under the microscope as thin needles. Coalescence of these plates is much more difficult to accomplish (in comparison with the carbon precipitation products); a nitrogen hardened steel is therefore not so sensitive to a drawing operation and starts to lose hardness at tempering temperatures considerably higher than though carbon were the active element.

Experiments to determine the exact influence of nitrogen have mainly been conducted with specimens at different temperatures in a current of ammonia gas. But little nitrogen is contained in the steel as a result of the melting process, although its effect is by no means negligible, and it is very difficult to separate its
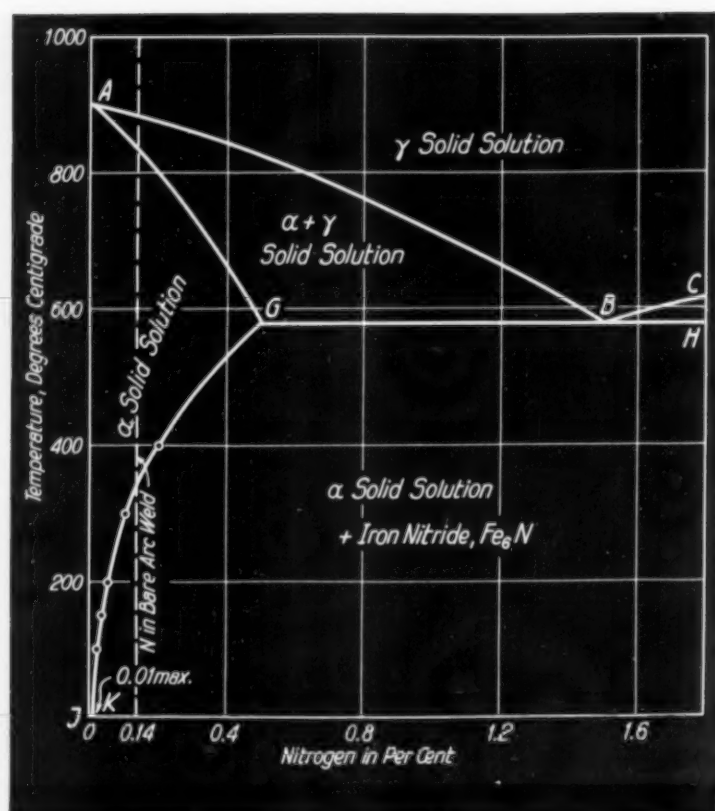
*Nitrogen Is Much More Soluble in Alpha Iron Than
Carbon at the Transformation. Its effects are easily
seen in arc welds and electric furnace steels
(some think the nitride is Fe₄N)*

action experimentally from that of other alloy-
ing elements. Although rather self-evident, it
may be pointed out that it is not likely that
nitrogen is absorbed in the usual hot working
operations in a steel mill or in the usual subse-
quent heat treatment.

In commercial steel the nitrogen content
amounts to 0.005 to 0.020%. In order to experi-
ment on the effect of nitrogen, specimens with
contents up to 0.5% nitrogen have been pro-
duced. In one series of tests, where an electro-
lytic iron was remelted in vacuum and annealed
in ammonia gas so that a nitrogen content of
about 0.5% was obtained, the following changes
in physical properties were recorded:

Heat Treatment	Elastic Limit	Tensile Strength	Elon- gation	Re- duction of area
Original	22,000	37,600	48	87
Nitrogenized and slowly cooled	22,700	40,400	35	81
Nitrogenized and quenched from 550° C.	28,400	44,700	..	..
The above, tempered at 250° C.	24,500	45,300	30	80

Mechanical properties therefore
change similarly to those caused by
carbon, but the influence of nitrogen is
not so pronounced. There is, however,
another phenomenon that is important:
Precipitated iron nitrides make the
steel very brittle. This brittleness is
present immediately after the quench
and even a long aging has a compara-
tively small influence in mitigating it.

That age has an influence — al-
though slight — on the physical proper-
ties has been shown by several tests.
In one experiment a steel with an
original hardness of 100 Brinell was
annealed in ammonia at 550° C. and
quenched. The hardness measured
immediately after the quench was 200
Brinell and after 28 days it was 250.

The influence of nitrogen on mag-
netic properties is more important than
its influence on the mechanical. Note
the following results obtained with
electrolytic iron:

	Original Condition	After Nitrogenizing
Coercive force	15 gilberts	4 gilberts
Residual induction	5,850 gauss	9,500 gauss
Conductivity	9.28	8.8

The injurious influence of nitrogen (that
is, the increase in hysteresis losses) will be felt
when nitrogen-bearing steel is used for electrical
purposes — such as sheet steel for electrical
motors and transformers. Although the content
of nitrogen in commercial steels is much lower
than in the test specimens, it is quite high
enough to exert considerable influence. Steel
used for electrical purposes usually has a very
high silicon content and is as low in carbon as
is commercially obtainable. Steel of this type
is often deoxidized with aluminum, and it is
apparent from a number of published nitrogen
analyses that material of this character has a
comparatively high nitrogen content. Nitrogen
has, moreover, a rather strong tendency to
segregate; one portion of an ingot or billet has
a nitrogen content three to four times as high
as the rest. It may also be stated that alloy
steels, especially when the alloying element is
chromium, are more likely to contain residual
nitrogen in injurious quantities than plain car-
bon steels.

Another interesting conclusion which may be drawn from a study of the published nitrogen analyses is this: Steel produced in arc furnaces almost always shows a higher content of nitrogen than steel produced in open-hearth furnaces. This really is not surprising, as the electric furnace arc is more likely to contain nitrogen in ionized or active form than the atmosphere in an open-hearth furnace. In the writer's experience, an open-hearth steel is decidedly preferable to a steel of the same analysis produced in an electric arc furnace. There is hardly any doubt but that this superior quality is due to the lower nitrogen content in the metal made in the open-hearth.

Many have been the arguments between adherents of bessemer and open-hearth steel. Bessemer steel has often been preferred in Europe for rails because with the same analysis (low phosphorus) it gives rails that are somewhat stiffer and have better wearing properties. The explanation is likely to be the difference in nitrogen content and an induced age hardening effect. Nitrogen content is usually four to five times as high in bessemer steel as in open-hearth, and will reach a value up to 0.020%, quite high enough to cause a considerable precipitation hardening effect.

It must also be remembered that in low carbon steels, carbon and nitrogen will combine to effect an age hardening.

Copper in Iron

The iron-copper diagram has the following characteristics: Solubility of copper in iron is 3.4% at 810° C., and about 0.4% at room temperature. This solubility of 0.4% is almost constant up to 600° C. but then increases rapidly.

Copper, as the active element in precipitation hardening, differs considerably in its action from that of carbon or nitrogen. A comparatively fast rate of cooling is required to keep the latter two in metastable solution, and the age hardness is lost at comparatively low tempering temperatures. On the other hand, the speed of cooling is of very little importance to develop the effect of copper, but tempering at comparatively high temperatures is essential. A copper-bearing steel may even be allowed to cool in the annealing furnace, provided the time

from maximum temperature to room temperature does not exceed seven or eight hours, without losing its ability to attain subsequently the maximum hardness increase by proper tempering. In regard to tempering temperature: The maximum hardness is obtained at 500 to 550° C.; a temperature up to 400° C. does not cause any hardening.

Results may be illustrated with a steel of this analysis: C, 0.15%; Si, 0.41; Mn, 0.97; P, 0.024; S, 0.029; Cu, 1.1; and Cr, 0.38. The "untreated" samples in the adjoining table had been subjected to previous hot-working operations at the usual high temperatures, in which the copper was brought into solution and did not precipitate on cooling. This did occur in the annealed or "treated" specimens, annealed for one hour at 500° C. and allowed to cool slowly in the furnace.

	Untreated	Annealed	Change
Tensile strength	82,500	98,000	20% gain
Yield point	55,500	74,000	32% gain
Elongation	22%	19%	12% loss
Impact test	12 kg-m.	9 kg-m.	25% loss

Copper-Bearing Steels Become Hard After Cooling Slowly From Annealing Heats. Ultimate strengths of 100,000 lb. per sq.in. in mild boiler steels can accordingly be secured
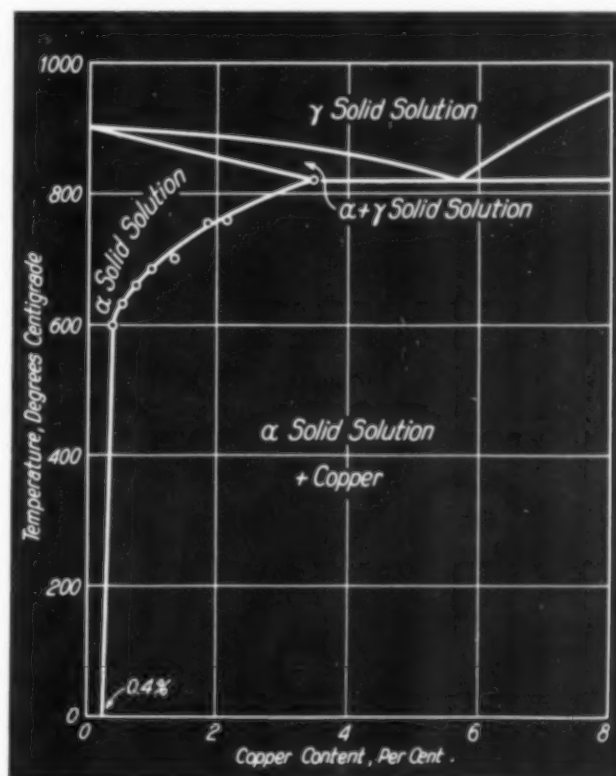
Even larger changes took place in a basic medium steel with a much smaller amount of copper: C, 0.29%; Si, trace; Mn, 0.60%; P, 0.026; S, 0.036; and Cu, 0.14. Similar tests were made to the ones described above:

	Untreated	Annealed	Change
Tensile strength	65,300	83,600	28% gain
Yield point	43,200	61,700	45% gain
Elongation	25.0%	15.5%	32% loss
Impact test	17.5 kg-m.	7.2 kg-m.	58% loss

Maximum strength is obtained after tempering at 500 to 550° C. for one to three hours, or at 450 to 500° C. for four hours.

A Valuable New Alloy

The practical importance of copper-bearing steel of this type for boiler plates and similar applications is quite obvious. In order to increase the strength it is advantageous to add 0.4 to 0.5% chromium to the analysis, and with properly treated chromium-copper alloy steels it is possible to obtain tensile strengths up to 100,000 lb. per sq.in.

Steels of this type can therefore in many cases compete with the tough annealed chromium-nickel steels for high duty applications. It is also possible that copper steels, with or without addition of other alloying elements, may be widely used for high duty steel castings which cannot be quenched. Many forgings or other machine parts present troublesome problems in the quench; alloys which can be hardened after deliberate treatments involving rapid cooling will be welcome there.

The three elements, carbon, nitrogen, and copper, are so far the only ones known to have considerable influence on the precipitation hardening of steel. Experiments with a large number of other elements have been made, such as chromium, nickel, tungsten, and beryllium.

Definite data are so far not available upon nickel and chromium in percentages such as are present in commercial carbon steels.

Influence of Tungsten

The importance of tungsten lies in the possibilities of improving high speed steel by utilizing the precipitation hardening theory. The well-known increase in hardness obtained by tempering properly hardened high speed steels has long been known and

Would You Work In Russia?

MANY engineers and constructors from the metal industry have gone to Russia to lend aid to the "five-year plan," and many have been the debates which argued the question of whether such employment is desirable, or even defensible. Those who frown on such expeditions are usually older men, well employed, who dislike the Soviet government and who fear cut-throat competition from future Russian exports.

Doubtless these forebodings will hinder few of the younger men from accepting a desirable contract in the U.S.S.R. In going over they will expect to live a rough-and-ready life, lacking all the luxuries and even many of the so-called necessities of life in America. Far from being a drawback, such conditions have always attracted adventurous souls to the frontiers of civilization. Amtorg, the commercial representative of the Soviets in America, has so far honored the letter of its contracts, and an employment agreement signed by it, which is definite in its provisions, is reasonably sure to be carried out.

Men of the age and type who would be attracted by such employment would seldom be deterred by doubts as to whether the effect of their endeavors would ultimately boomerang to their own and their country's disadvantage. As a matter of fact, it would seem that this eventuality, while not impossible, is improbable, at least for several decades.

For example, consider the expansion in the steel and iron industries. Present Russian capacity for producing pig iron and steel is somewhat greater than pre-War figures, but it is to be tripled by 1933. At that date, the Soviet plants, new and reconstructed, will have an annual capacity of 17,000,000 tons of ingots. This does not seem so overwhelming when it is remembered that her population of 160,000,000 is considerably greater than our own, whereas

we find reason for maintaining a steel capacity $3\frac{1}{2}$ times as great. Stated in another comparison: At the fulfillment of the five year plan, each Russian will have a steel supply equivalent to what each American consumed in 1890!

Certainly, all the iron and steel the U.S.S.R. can produce will be needed for internal developments; many years will be required before she will be even meagerly supplied with modern housing, tools, roads, railroads, power plants, automobiles, agricultural machinery, and chemical plants. As the designer of one of the biggest of the new steel works puts it, that mill can wear itself out making nothing but rails, and even then Russia would lack a reasonably good railroad system. Does it not seem fantastic to shudder at the "threat" of Russian automobiles because they have a plant capable of making 140,000 Fords a year? By the time they can export any Model A's, every American will be wanting an 8-cylinder car!

In other words, normal competition in world markets for manufactured goods, especially machinery, demands not only natural resources but a population of inventors and mechanics and salesmen capable of understanding the customers' wants and also of fulfilling them. Russia is not such a country, and will not be such a country for a long time, if ever. Lacking these the cheapest labor would be of no avail.

It is, in fact, a common experience of engineers working in backward countries that cheap and ignorant labor is not efficient, and does not produce more cheaply than expensive, skilled labor. When ignorant labor becomes educated and skilled, it is no longer cheap. Of course, the outcry today against Russian labor is that it is the same as convict labor, therefore, production costs over there cannot be computed on a dollar basis, and exports can be dumped at any price that will bring a sale.

Evidence multiplies, however, that this
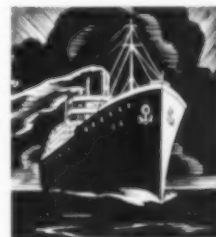
dumping of wheat, butter, coal, petroleum, and other commodities is a temporary expedient necessary to finance the imports of foreign brains and machinery required by the country's industrial rehabilitation. Since we will not loan them the actual money required to finance these improvements, we should be prepared to absorb the equivalent in goods.

This whole Russian question may be summed up in the thought that our men and machinery are lending a hand to millions of human beings arising from centuries of oppression. If the rest of the world, having all the advantages of centuries of material progress, cannot safely and speedily admit this new-born nation into a harmonious relationship, then it is time something is done to repair our own governmental and economic systems.

Opportunities
at Boston

SEPTEMBER marks the annual meeting of the American Society for Steel Treating. As everyone should know by this time, it is to be held in Boston the week of the 21st. Choice of the site fortunately puts the gathering in a part of the country where the harbingers of business revival (oft heralded in these recent months) seem finally to have arrived in a gratifying activity in the leather, shoe, and woolen industries. Our professional or habitual business prognosticators seem fairly well agreed that activity in such basic trades, close to the ultimate customer, is a real indication of future developments.

Hopeful anticipation should therefore pervade the atmosphere in Boston, supplementing the enthusiasm for new ideas about metal and its treatment which has always been the feature of A.S.S.T. meetings. No effort has been made to "play up" the convention in these pages, for that has been done properly in *The Review*

and the friendly technical press (and a prime editorial principle of METAL PROGRESS is to avoid duplication of effort). A record-breaking amount of technical material will be available. In fact, nearly a dozen of the papers have been printed in these pages in order to relieve the printing office of a little of the burden of publishing 55 contributions in advance.

Practical Effects
of Gas in Steel

IN THIS and previous issues of METAL PROGRESS more than one mention has been made about the effect of small amounts of gas in steel and of almost infinitesimal quantities of more easily determined chemical elements. More will be said about it in future months. Lest this be set down as a mere excursion into unexplored scientific territory, the reader ought to paste in his hat the prediction that when this unknown realm is properly explored we will find therein the reason for the changing ductility of deep drawing sheet, the stiffening of cold drawn wire, the caustic embrittlement of high pressure boilers, soft spots in case hardened steels, varying susceptibility of tool steel to the quench, and temper brittleness. Certainly these things are "practical" enough for anybody, and the ability to avoid or control the various effects would repay handsomely the cost of the necessary researches.

Many metal men have a well-defined suspicion that oxygen, either dissolved in the iron or chemically held in scattered slag particles, is responsible for the irregular hardening phenomena and those structural conditions commonly called "fiber." Rigid proof has been difficult, since no simple and accurate analytic method for oxygen and oxides was known, but one of the useful by-products of the Pittsburgh studies into the physical chemistry of steel making is such a method. Eventually we'll have

more quantitative information about the existence of oxygen and its effect.

Nitrogen is another suspicious character. In all commercial steel-making operations the hot metal is exposed at times to this gas; but it is ordinarily assumed that the element is so inert chemically that none is combined or even absorbed. However, in the making of arc welds, the highly superheated iron is in close contact with nitrogen, probably ionized to a degree that its chemical activity is enormously increased; the result is that a very pure deposit (at least as far as carbon and the other commonly determined elements in the weld metal are concerned) is full of microscopic plate-like substances, and has tensile properties and hardness far different from iron of similar composition made in an open-hearth furnace.

Hardening in cyanide baths by a combination of carbon and nitrogen is an old, old story. Nitrogen hardening of special alloy steels is one of the recent important advances in the metal industry. Dr. Westgren has shown by X-ray studies the many chemical and crystallographical similarities of the metallic carbides and metallic nitrides. In the present issue are articles by E. W. Ehn and Messrs. Hensel and Larsen which show how either carbide or nitride has a powerful effect on the strength of iron after quenching and tempering, each acting by exactly the same mechanism.

Scientists abroad believe that the hardening of sheet steel with aging, such as noted by Mr. Cox on page 85 of this issue, — an extraordinarily troublesome phenomenon in deep drawing work — is due in great part to the precipitation of insoluble substances from the ferrite crystals. Even carbon appears to be somewhat soluble in ferrite at the transformation temperature, and this solubility decreases as the temperature drops. The iron crystals in an air-cooled sheet, therefore, have within them foreign substances which separate slowly even at room temperature, "key" the slip planes of the ferrite crystals and thus harden the sheet and reduce its ductility materially.

Other substances with similar effect, such as indicated in E. W. Ehn's article on page 59, might be eliminated by the steel maker, but the carbon is with him always. Pending the discovery of some alloying element which will create a false stability of carbon in ferrite, one way to avoid sporadic cracking is to do the deep drawing within a few hours of the time the sheet comes out of the last anneal or normalize — probably in the steel mill itself — thus performing the cold work before the inevitable hardening can occur. Messrs. Winlock and Lavergne, in a paper for the Boston convention published in this issue, show how the speed of deformation and the time and amount of preparatory cold work, also have an important bearing on the problem.

It was suggested by Dr. Robert F. Mehl at a meeting of the Ontario Chapter last fall that the gradual hardening of cold worked metal and "blue brittleness" might also be due to the same cause as noted — namely, the precipitation of excess constituent in the slip planes; in these latter two phenomena the action is accelerated by the cold work which has been done prior to the test or spontaneously while the test is going on.

Even though the interrelation of all these unexplained metallurgical puzzles is only surmised as yet, the tentative generalization will undoubtedly prove suggestive to the workers in this field. Heretofore, about all that could be done about the aging of sheet steel or hard drawn wire was to collect data about its occurrence, and use this hoard of experience as a guide for action. In the future we will be able to check performance data against the gas content of the steel and the date and nature of its final heat treatment.
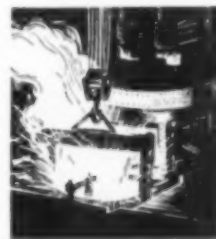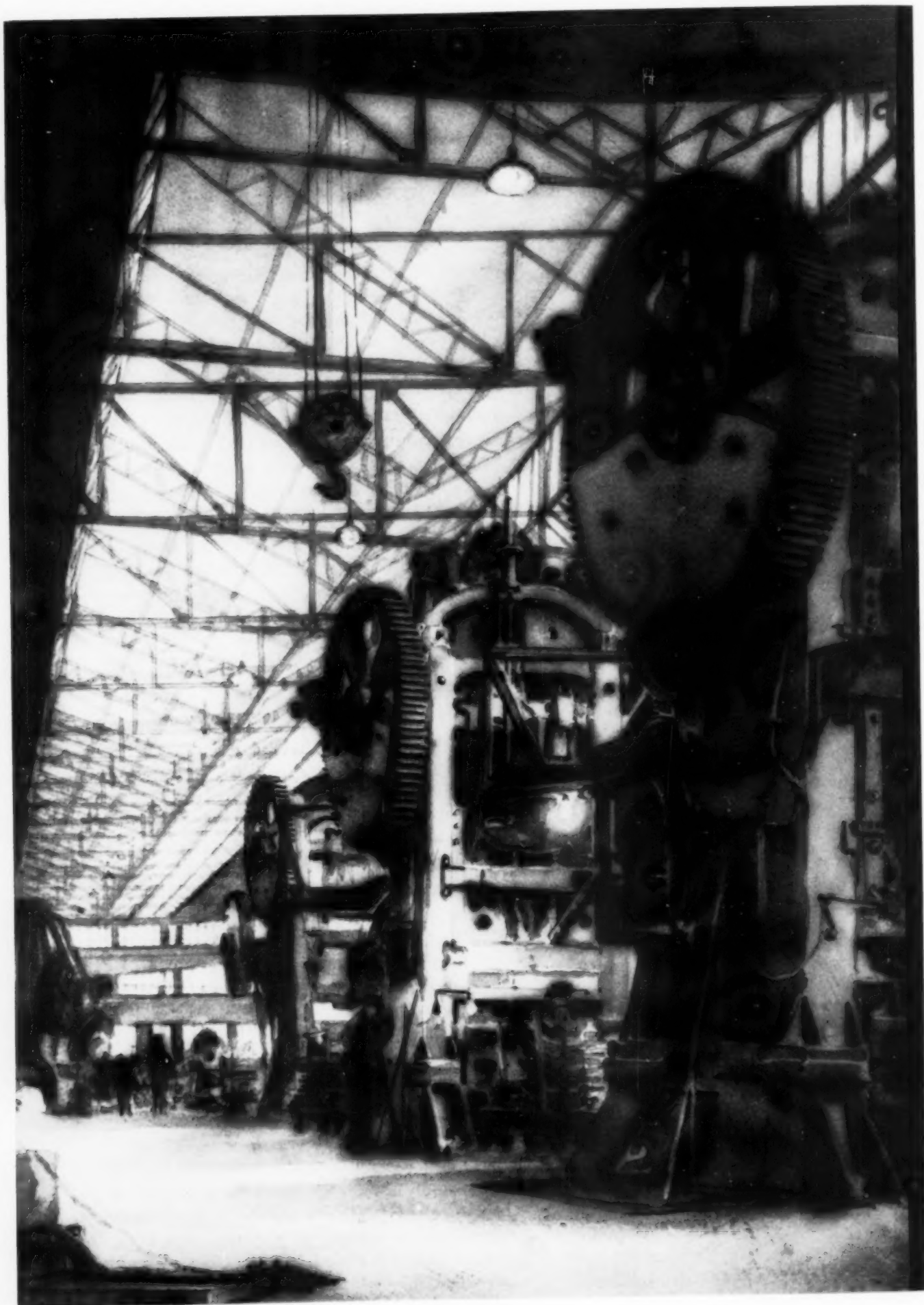
From Water Color by Edward D. McDonald

Giant Presses

By Maurice Reswick

Chief Engineer,
Pennsylvania Lubricating Co.,
Pittsburgh

Lubricants for

Deep

Drawing

A paper for
the A. S. S. T.
Convention

FUNDAMENTAL processes involved in stamping and drawing of metals are those of plastically working the metal at ordinary temperatures in compression or squeezing, and in tension or elongation, subjecting it to local stresses beyond the yield point without exceeding its ultimate strength.

Depending on the relative stresses involved, the degree of working may be classed as ordinary stamping, shallow drawing, deep drawing, extra deep drawing, and extra-extra deep drawing, referring to each step or press operation. In this paper, the operations usually understood as "deep drawing" will be considered, in which the plastic stresses approach the ultimate strength of the sheet steel, so that any deductions arrived at may be readily applied to the less severe cases.

Lubrication in metal drawing is still regarded as being a secondary consideration to the design of machinery and dies and to the improvement in production methods. Some operators regard it a necessary evil instead of a useful function in the conservation of dies and as a means of improving the output. Until recently, each fabricator developed his own lubricants by the expensive cut-and-try method.

The literature is abundant with engineering informaton and operating data, but there is an obvious scarcity on the vital subject of lubrication. This is due in equal measure to the failure of the metal fabricator to appreciate the scientific phase of this subject and to the reluctance of the lubricant manufacturers to disclose "trade secrets."

As the development of an efficient lubricant depends on the science of chemistry and the art of compounding as much as it does on a knowledge of the operating problems involved in the drawing of sheet steel, it is obvious that the problem can be best solved by mutual effort and by the technical staff of the manufacturers who make a specialty of developing special lubricants for particular jobs.

The primary function of a lubricant is to prevent metal-to-metal contact between the work-piece and the dies, and also to decrease the sliding friction to a minimum. The degree to which a lubricant comes up to these requirements is a measure of its efficiency and value.

The most satisfactory procedure in purchasing is not on the basis of analytical specifications nor on prescribed laboratory tests, but on the basis of satisfactory performance on the job. Accordingly, an ideal lubricant which meets the requirements of deep drawing operations, must possess the following characteristics in the order of their importance:

1. *Film Strength.* The film or coating must be strong enough to withstand the enormous pressure prevailing within the plastic range of the worked material under compression, so as to prevent metal-to-metal contact both under static and flow conditions of the worked metal. Scoring and abrasion of the dies and work-piece must be prevented, as well as "pick-ups" of the softer metal on the hardened die surface (the result of actual fusion of surfaces in direct contact, due to the intense localized heat momentarily generated from friction). Aside from the heat due to rubbing friction, there is also that due to the plastic deformation of the metal worked; it is essential that the lubricating film must not be unduly thinned down and weakened at the higher temperature.

2. *Oiliness.* Coefficient of friction between die surface and work-piece must be low, so a minimum amount of energy is expended in skin friction, both in the forward or working stroke and in the pull-back. Lack of oiliness results in localized drawing, or in uneven elongation and wall thickness. Steel sheets of light gage, especially in flanging operations, break and develop seams and cracks when a poor lubricant is used.

3. *Adhesiveness and Spreading.* The lubricant must adhere to the surface of the metal without being unduly tacky, and spread itself under pressure in such a way that it will form a protecting film *ahead* of the working portion of the die. It should also be sufficiently light in body and possess marked affinity for the metallic surface, so it may be applied manually by a brush or mechanically by an automatic spraying device or plastic gelatin-like rolls.

4. *Ease of Cleansing.* As the stamping must generally be plated, tinned, galvanized, lacquered, or painted, it is essential that all traces of the lubricant be easily removed by a readily obtainable and cheap cleanser, such as a simple mixture of caustic soda. This requirement is generally met in a drawing compound that emulsifies in water.

5. *Non-Corrosiveness.* The lubricant must not contain mineral acids that attack the metal should the cleansing process be delayed, nor should there be any tendency to pit the surface of the expensive dies.

6. *Stability and Uniformity.* The drawing compound must be stable in composition — no separation into its component parts during storage and handling — nor should it become rancid or decomposed. One shipment must be exactly the same as the previous shipment.

7. *Physiological Effect.* The lubricant must be absolutely neutral in its physiological effect on the machine operators, and must not contain any ingredients which may poison through skin absorption or inhalation of fumes, nor shall it produce such skin diseases as pimples, eruption, or boils. It ought to permit the introduction of a harmless antiseptic like creosol.

8. *Odor.* No perceptible disagreeable odor should be noticed. Perfuming substances, to disguise the real odor, should be avoided.

9. *Resistance to Climatic Conditions.* There should be no pronounced change of its consistency or other properties with the usual variations of temperature and humidity between summer and winter.

10. *Economy.* The drawing compound must be low in cost. With some metal fabricators this item is of first consideration. Logically, the relative cost of the lubricant should be regarded not on the basis of its price per pound or per gallon, but on the basis of its cost per thousand pieces finished, considering also the quality of the product and the wear on the dies and tools. An appreciable saving may be effected by purchasing a lubricant not only of the best quality for the purpose, but also in the most economical form. For example, a certain manufacturer in the Middle West was able to reduce his lubrication cost by more than 50% through the simple expedient of purchasing only the "base" of a soluble compound and by diluting it at his factory to the proper consistency, thus avoiding freight charges across several states on an abundant commodity like water.

A drawing compound that would meet the above ten requirements 100% is the ideal to which we are striving, and which the users are hoping to get sometime before the millennium. Unfortunately, in the art of making compounded lubricants like grease and drawing compounds, a particular characteristic in the finished product is usually obtained only at the sacrifice of another, often equally important. Hence, the best it is possible to produce consists of a compromise, and the skill exercised

in the compounding of a lubricant that would possess the greatest degree of advantage is what differentiates one lubricant manufacturer from another in the same business.

Specific Purpose Drawing Compounds

While a so-called general purpose compound may be prepared that will suit three out of four deep drawing operations more or less satisfactorily, it is realized that working conditions vary greatly, and out-of-the-ordinary situations are frequent. The complexity of the work-piece, design of dies, wall thickness, speed of operation, kind of metal or alloy used, surface characteristics, physical properties, and evenness of anneal are all factors which must be considered. Low-carbon steel, higher carbon

steel alloys, stainless steel, brass, and aluminum require different methods of handling; for a first-class job the lubricant used must also be modified accordingly.

For light work, whether in ordinary stamping or in deep drawing, a simple compound of a soluble oil is all that is necessary. For heavier classes of work, special lubricants are required. Some of the lubricants used in drawing steel are decidedly unsuitable for aluminum, for which the compound must be free from alkali.
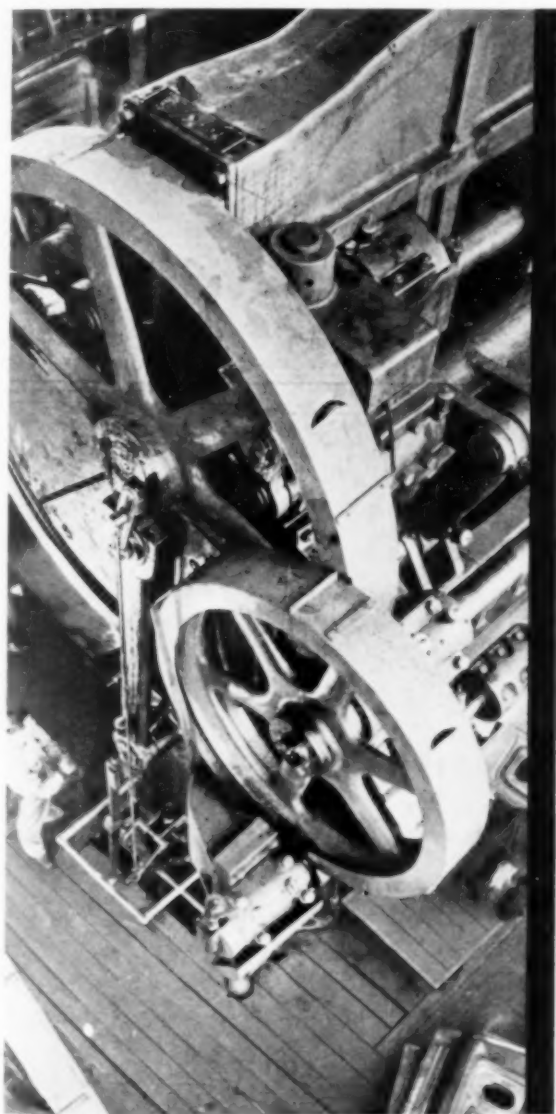
On some work powdered copper, or even sheets of paper are used, in the absence of a better lubricant, to separate the die from the work during the draw. These simple expedients are better than no lubrication, but more efficient lubricants have been developed and have received adequate tests in the field to establish their merits.
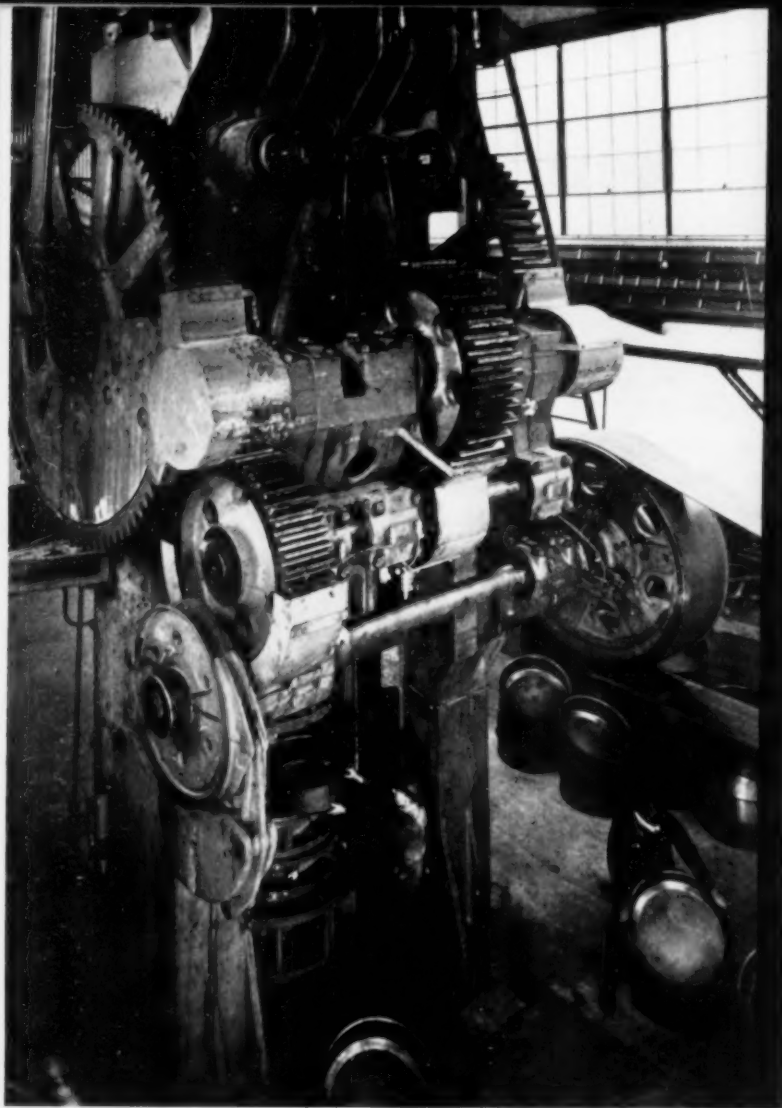
The principal ingredients will now be enumerated and an effort will be made to state their functions, giving the reason why they impart certain characteristics to the lubricant.

1. *Tallow.* This is the oldest and still most extensively used ingredient. In its raw state, it is a lubricant of the first order, but its inherent properties are brought out to best advantage when it is combined in the form of soap with certain metals such as calcium, sodium, potassium, lead, aluminum, and zinc. The addition of tallow or other animal fats to any lubricant enhances its oiliness, increases its film strength, and makes it adhere to the metallic surface better. In press work, it is claimed that tallow follows ahead of the die, creating a lubricating film on the surface of the work-piece before the die penetrates or comes in contact with fresh surfaces.

In the raw state tallow is inconvenient and objectionable, because it tends to become rancid and wormy. It is difficult to apply to large work, while modern conditions of speed and pressures demand that its inherent properties be still further enhanced. Furthermore, tallow and other animal fats and oils in raw state cost more than compounded lubricants.

In the same class with tallow, other fats and fixed oils like lard or palm oil may be mentioned. The best drawing compounds contain the best grade of these fats, especially those having a high melting point.

What is Said to Be the Largest Deep-Drawing Press in America, Built by Toledo Machine & Tool Co. for Lalance & Grosjean Mfg. Co., Long Island City, N. Y., for Making Milk Cans from High Chromium Sheet (Allegheny Metal)

excess over the requirements of emulsification may be regarded as a diluent controlling the consistency of the drawing compound.

In order to clean the stamping, the mineral oils, animal or vegetable oils, and all other ingredients are combined in such manner that they are of a soluble nature, or are a colloidal emulsion. This is usually accomplished by introducing a soap, like soda or potassium soap, which dissolves in water.

4. *Fillers.* Filler materials like chalk, soapstone, mica, rosin, graphite, fireclay, potters' clay, or borax are objectionable in a grease used for the lubrication of general machinery, and standard specifications outlaw these adulterants. In drawing compounds, however, where the relative speed of the rubbing parts is extremely slow, and the coefficient of friction is not necessarily required to be at a minimum, the presence of fillers is not only permissible, but even desirable. These fillers, while they coarsen and cheapen the grease, serve the useful function of increasing the strength of the lubricating film by the simple expedient of thickening the film, so that a greater pressure acting over a longer interval of time will be required to rupture the film. These fillers are also somewhat unctuous in their nature, or slippery to touch, but most of them do not possess any pronounced lubricating properties. Fillers like mica and graphite perform the further function of acting in a limited degree as solid lubricants, the claim being made that even when the mineral or fatty lubricating film is broken down, the graphite or mica still prevents metal-to-metal contact. Fillers also fill the low spots on the metallic surfaces of the work-piece, and reduce the possibility of scratching the die or causing a pick-up. Necessary fillers should be used in a highly pulverized form, so their abrasive action is reduced to a minimum.

Certain fillers, like soapstone and chalk, may be present in combined form with the other ingredients of the drawing compound. Even when they are in free state, they are not difficult to remove with a caustic soda cleaning fluid. However, fillers like graphite (chemically inert substances) cannot be washed away readily, especially since minute particles of graphite are likely to become embedded or anchored into

2. *Mineral Oil.* Nearly every lubrication job requires the use of mineral oil in one form or another. In general, the greater the viscosity of the oil, the stronger is the film strength and the greater is the adhesion to metallic surfaces. Too much mineral oil should be avoided in a drawing compound, else the product cannot be cleaned with simple mixtures like caustic soda. Special cleaning compounds like benzine, naptha, and other solvents must then be used. Hence, the mineral oil should preferably be in combined form with other ingredients, like soda base soap and other emulsifying substances of a similar nature.

3. *Water.* Water is present as an emulsifier, wherein it serves the function of a binder between the animal oils, mineral oils, soaps, and other ingredients. A definite percentage of water is necessary for this true function; any

the microscopic "pores" of the metal. Hence, in general, the amount of graphite and mica should be limited to very low quantities; when the drawn or pressed product is to be electroplated, fillers of this type must not be used.

"Border-Line" Compounds

Within recent years startling progress has been made in the field of general lubrication by developing oils and greases containing lead oleate. Experiments are now in progress with this ingredient in drawing compounds.

Lead oleate compounds are known as "border-line" lubricants and may be best defined graphically by the sketch below (based on actual tests) showing a straight mineral oil and a lead oleate compound, both having the same viscosity. A good lubricating film was maintained with the mineral cylinder oil until the load reached 7,000 lb. per sq.in., at which load the coefficient of friction began to rise rapidly. Between 8,000 and 10,000 lb. per sq.in. the film was practically all squeezed out. The "border-line" is, therefore, indicated at 7,000 lb. per sq.in. of load. At loads below the "border-line," there was perfect fluid friction; beyond the "border-line," lubrication was only partial at first, resulting in semi-solid friction, while at the 10,000-lb. load solid-to-solid friction was approximated. Hence, it is not safe to exceed a unit pressure of 7,000 lb. per sq.in. with straight mineral oil.

While the coefficient of friction for the lead oleate compound was slightly higher from the start, effective lubrication was maintained until a pressure of 45,000 lb. per sq.in. was reached! In other words, the protection obtained was over six times greater than with mineral oil.

Several analyses of typical drawing compounds on the market are tabulated above. They are given through the kindness of H. F. Lefurgy, chemist, Pennsylvania Lubricating Co. These are not formulas which may be used in their manufacture, but are merely laboratory analyses which may be made by any chemist. The figures give only an approximate idea of what the various constituents are, but they fail to reveal the more essential information as to how the various ingredients are combined. Two chemists using the same formula will produce

Proximate Analysis of Drawing Compounds

	I	II	III	IV	V
Unsaponifiable matter	20.9			49	
Unsaponified neutral fat	7.6	50.2			
Free fatty acid	6.7	12.4		3	
Sodium soap	23.8		54		
Potassium soap		5.9		18	
Lime soap					6
Mineral oil					22
Mineral filler					40
Water	41.0	31.5	46	30	32

two products which are different from each other in stability, lubricating properties, and even in appearance. Many factors are involved in the actual manufacture, such as temperature control, the order in which the ingredients are mixed to prevent internal chemical interaction, and the skill required in making successful emulsions and colloidal suspensions.

Unsaponifiable matter used in I was a mixture of cylinder oil and petrolatum, while the fatty material was apparently a mixture of palm oil and tallow.

In II no mineral oil was present and the fatty material was a low grade tallow of rather poor odor.

No mineral was present in III; neither was there any unsaponifiable neutral fat or free fatty acid. The fatty material used in the soap was a mixture of vegetable oil and animal fat.

Unsaponifiable matter in IV was a red engine oil having 300 viscosity at 100° F. The fatty material was elaine oil.

Mineral oil used in V was a pale product having a viscosity of 190 at 100° F. Fatty material used in the soaps was an animal fat of low melting point, and the mineral filler was of the colloidal clay type.

Lubricating Film of Lead Oleate Stands Up Under Loads Six Times as Heavy as Cylinder Oil Can Carry
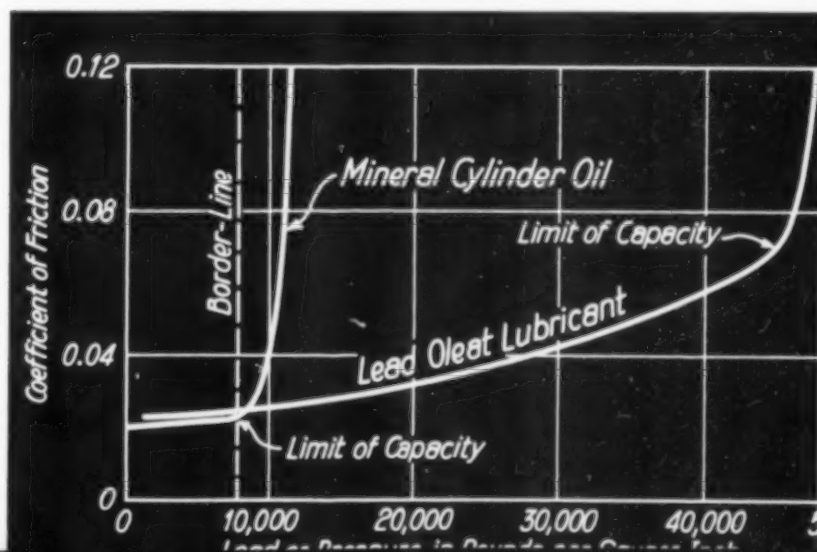
By Murray Winter
Supt., Winter Brothers Co.
Wrentham, Mass

what

is a

Neutral

Atmosphere?

SO MUCH has been said and written about the heat treatment of high speed steel in the past 20 years that it might be thought that the subject has long since been worn threadbare. In fact, it might appear difficult just now to find anything new to say about the hardening of lathe tools, for instance. But even this relatively simple operation is being studied to discover the best method to obtain the maximum useful work from each tool.

One important class of high speed tools which has been given close study for several years includes drills, taps, and reamers. Hardening problems are especially intricate when the smallest sizes are being treated. As a result of the above-mentioned studies several new ideas regarding different phases of the operation have been evolved, and are being practiced with satisfactory results even on tools of moderate and large size. It is perhaps not too much to expect that the next few years will witness a pronounced modification in accepted best practice for heat treatment of high speed steel articles.

Our interest in this general problem of hardening started in 1902, when Winter Brothers Co. first started manufacturing taps and dies in Wrentham, Mass. For a long time, all tools were heated in a gas or oil-fired muffle. The best combination discovered was a brick-lined steel shell into which two chambers were placed, one immediately above the burners and the second still higher up where it was heated by exhaust gases. The upper chamber was for preheat; the lower for high heat.

Much skill was required to operate these muffles so the small tools of high speed steel would be properly hardened. It was impossible to burn the gases in such a manner that a truly neutral atmosphere existed in the high heat chamber. That is to say, either some scale was present or else the tools had a soft surface. Therefore, as a little scale on this class of work is less objectionable than soft surface, the operators attempted to regulate the flame and the time at maximum heat so that this scale would be of a uniform thickness (say 0.001 in.) which was provided for by machining the tool 0.002 in. oversize. With good practice, it was possible to get a large percentage of small tools to correct finish-size after hardening, tempering, wire brushing, and grinding the flutes.

A small variation in furnace atmosphere, temperature, or time at heat which would not be caught in some tools would cause much trouble to a manufacturer of small taps or dies. A little too much scale and the lot would be undersize and ruined. Not enough scale and a second heat or an expensive lapping operation on the hardened tools would be necessary.
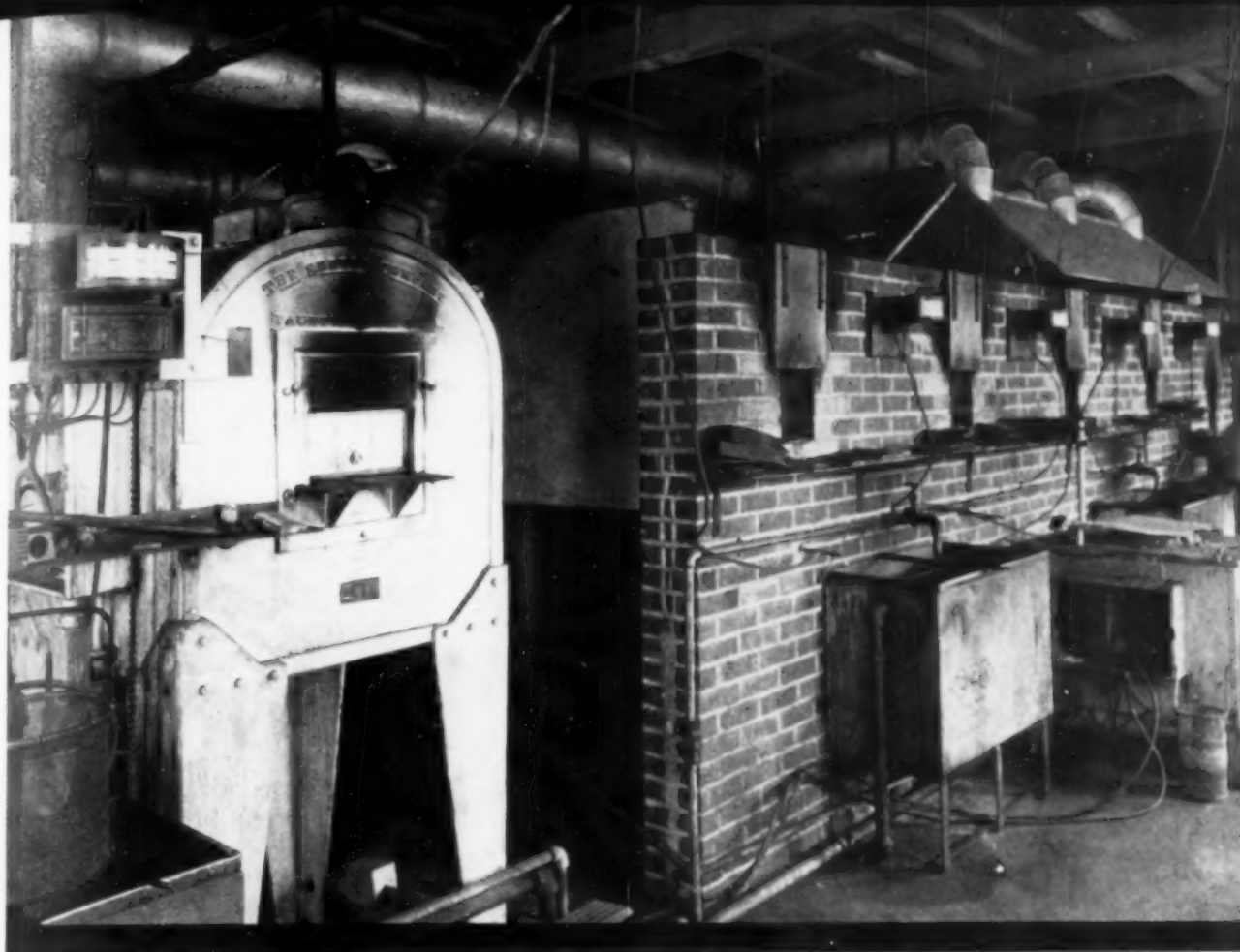
Salt baths were given an extended trial at Winter Brothers Co. and other methods of hardening were tested. Some of these methods showed a saving in lowering the number of tools rejected, and various expedients were under consideration when our attention was diverted to the "diamond block", a method of controlling the atmosphere in contact with the white hot steel which will be discussed in some detail later in this article.

We had operated an electric furnace for some time, and had utilized various coal and oil products in an attempt to produce a neutral atmosphere. The furnace was operated for some years with a gas connection and gas was supplied in various ways to exclude the atmosphere and to combine with any excess oxygen present in the furnace chamber.

Gas conditions inside the furnace produced various results, sometimes scale and blister, sometimes a soft surface, and occasionally tools with a fairly satisfactory surface. On account of the difficulty of controlling the atmosphere and uncertainty of results it was found desirable to maintain the atmosphere, time and temperature in such adjustment as to give a *uniform* amount of scale, much as was done in the oil and gas furnaces.

In order to determine the cause of these effects and to find wherein the neutral atmosphere obtained in "diamond blocks" differed from an atmosphere obtained from illuminating gas, a series of tests was recently run by us at the Sentry Co., Taunton, Mass., furnace manufacturers.

The perfection of heating elements of silicon carbide (known as globars) has at last enabled equipment to operate at 2,550 F. These heating elements have made possible the manufacture of electric furnaces to operate at temperatures sufficiently high to heat treat even the cobalt-bearing high speed steels, and, at the
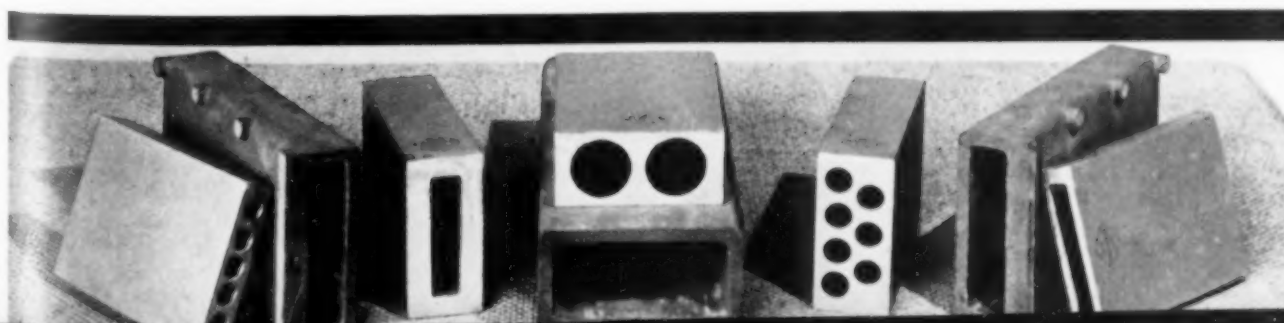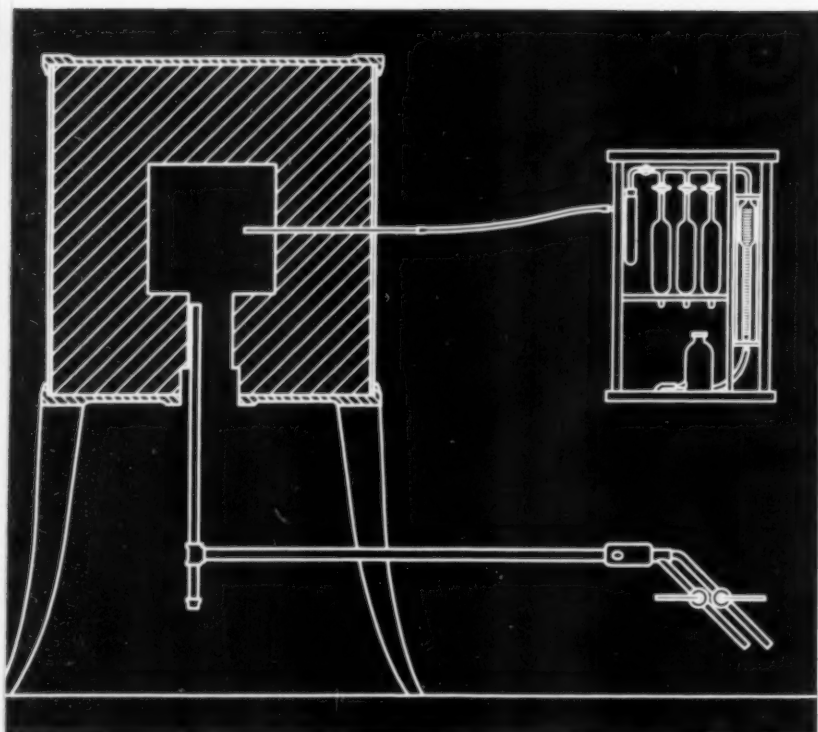
Diagram Showing the Experimental Electric Furnace With Bottom Opening. The method of introducing gas inside furnace and of analyzing the atmosphere is indicated

same time, have permitted the study of correct atmospheric conditions, independent of the many products of combustion hitherto present.

As shown on this page, the furnace was sealed except for an opening in the bottom through which the test pieces were passed. This arrangement confined the gas and reduced convection currents. Mixtures of air and illuminating gas were piped into the chamber. A small amount of gas and air was continually supplied so as to maintain a constant condition in the furnace chamber, and samples were analyzed for oxygen, carbon monoxide (CO), and carbon dioxide (CO_2) with the well-known Orsat apparatus. Prof. Augustus Gill of Massachusetts Institute of Technology cooperated in the gas analysis.

Gas was from the town mains and contained about 1% CO_2, 31% CO, and the balance principally hydrogen and methane (CH_4). The mixing valve connected to the gas line and the air main was adjusted for a slow flow; after this had been passing long enough for the conditions inside the muffle to be uniform, test pieces were introduced and the gases from the

muffle were analyzed. A series of tests was made with various proportions of incoming air and gas so that the furnace atmosphere contained all the way from zero to 30% CO. Temperature was maintained constantly at 2,350 F.

It was observed that the illuminating gas and air mixtures introduced into the muffle burned with a flame characteristic of the carbon monoxide content.

With a low percent of carbon monoxide the flame is quite transparent. At about 10% CO the gas burns in the supply pipe at the mixing valve. With higher or lower percentages, the heat of combustion would not maintain the flame at this point, but burning would occur in the furnace chamber. At 15% CO the flame becomes more reddish and less transparent and above 25% CO the atmosphere is very thick, dark red in color, and characterized by free carbon particles floating in the air and depositing on the walls; some of the furnace energy is apparently consumed in heating the gas.

Test pieces were small rounds of 18% tungsten high speed steel. These were threaded, as surface changes are more readily detected on a V-thread. Each sample was carefully calipered before heating and after quenching. Then the samples were filed to remove adhering scale (or soft skin) and again calipered.

Changes in size are shown on page 77, plotted against the gas analysis (amount of carbon monoxide in the mixture was selected as abscissæ). The dotted line indicates the change in size after hardening — that is, steel plus adhering scale. The straight line shows the change in size after cleaning off scale and soft surface. (It should be noted that the absolute change in size will depend upon the design of tool and its size and also furnace conditions.)

A series of these samples is represented on page 78. Pieces heat treated in an atmosphere of less than 12% CO showed considerable scale, and the surface was burned sufficiently to reduce the size. The surface condition of test pieces materially improved as the gas analysis approached 17% carbon monoxide.

Immediately on passing this point, the worst condition was encountered, and although test pieces hardened in an atmosphere of 17% to 25% carbon monoxide showed a beautiful satin black finish, still they possessed a soft

surface. A file easily removed the steel from those pieces to a considerable depth until a point was reached where the soft surface, showing in contrast with the hard steel below, was clearly visible to the eye.

With more than 25% CO, the test pieces had a good finish with no indication of scale, and the surface was hard to the file, showing no decarburization.

This curve shows only some mixtures of gas and air investigated; on the lower end of the curve carbon dioxide is present in decreasing quantities, but no carbon monoxide exists, due to excess oxygen. This condition cannot be plotted on a carbon monoxide base; it gives a very decided scaling, as would be expected.

With the illuminating gas used, the maximum carbon monoxide content that could be obtained is limited, and tests above 30% CO were not completed. However, sufficient work was done on this to reveal that a point exists somewhere above 30% carbon monoxide at which the steel starts to melt, probably due to the absorption of carbon and change in composition sufficient to reduce the melting point.

To summarize: In an atmosphere of partially burned illuminating gas, it is possible to harden high speed steel without decarburization and with a minimum of scaling when the carbon monoxide content is about 17%, but one containing from 17% to 25% CO will decarburize high speed steel rapidly at 2,200 to 2,400° F. Atmospheres containing from 25 to 30% CO are truly neutral; samples can be left in this atmosphere for a long time without surface changes.

What is the cause of these abrupt changes in atmospheric effects? It has been suggested that the scale which forms on high speed steel in atmospheres containing about 17% CO adheres closely to the steel and "glazes" the steel against decarburization. Hence we get scaling, but no decarburization. The deep decarburization existing between 17 and 25% of CO may be due to the ease with which decarburizing gases affect the steel when no scale is present. When the richness of the atmosphere is increased still further, the decarburizing and carburizing gases appear to be in equilibrium, as no change occurs.

These hypotheses are tentative, and possibly are true only in a general way. It is known, for instance, that a carbon tool steel heated in a gas-air atmosphere containing 10% CO will both scale and decarburize. Some of the cobalt high speed steels will also scale and decarburize at the same time, but can be hardened without soft surface in a very rich atmosphere of carbon monoxide. This seems to indicate that scale is not to be relied upon for surface protection, but that a sufficiently rich atmosphere will prevent decarburization.

Although these experiments were attempted in the hope of developing an electrically heated furnace in which the desired atmosphere could be produced with a hydrocarbon gas, they were not, in this respect, entirely successful. They indicate the desirability of a 25% to 30% carbon monoxide atmosphere, but when this condition was obtained numerous difficulties were encountered.

The atmosphere is then so dense that pieces placed in the furnace could not be seen to tell whether they had reached quenching temperature, and difficulty in removing them was experienced. The sooty carbon gradually in-

Change in Size of High Speed Threaded Rounds After Hardening in Atmospheres Containing Increasing Proportion of CO. All samples quenched from 2,350° F.
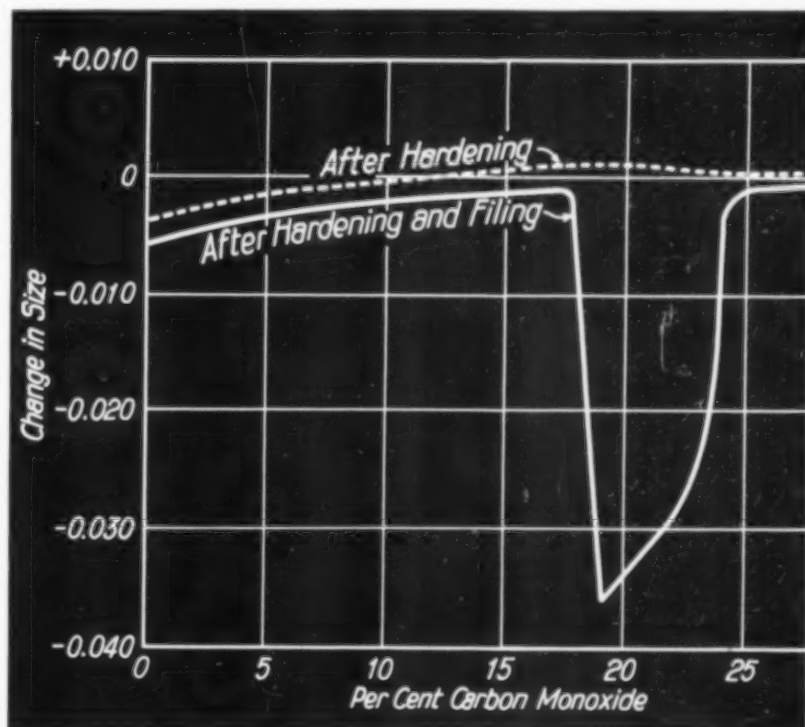
creased in volume until it acted as a conductor, short circuiting the electrical connections in the furnace. Furthermore, the vertical arrangement adopted to overcome convection currents was very awkward for anything but an experimental furnace.

All of these circumstances pointed to the desirability of producing a neutral atmosphere, high in carbon monoxide, by some other method.

Long experience at Winter Brothers Co. has indicated that "diamond blocks" offer this method. They produce an atmosphere of about 28% carbon monoxide and maintain this constantly within about 1% throughout their life, other gases being in such proportion as to maintain a balance between carburization and decarburization. This gives an atmospheric condi-

and other products on the slowly consuming surface of the block maintains the correct heat treating atmosphere at all times.

Tools hardened by this method have a gunmetal finish and have a surface film so thin that no allowance in size need be made for tools accurate to the nearest thousandth.

In practice in our plant at Wrentham a number of small taps are placed in the block and heated for about three minutes (or more depending on the size). Then the nickel tray is removed and the taps slide off into the quench. The nickel tray is then replaced and the operation repeated. One block will harden about 200 $\frac{3}{16}$-in. taps an hour.

Blocks are consumed slowly with an average life of about three shifts. This life varies
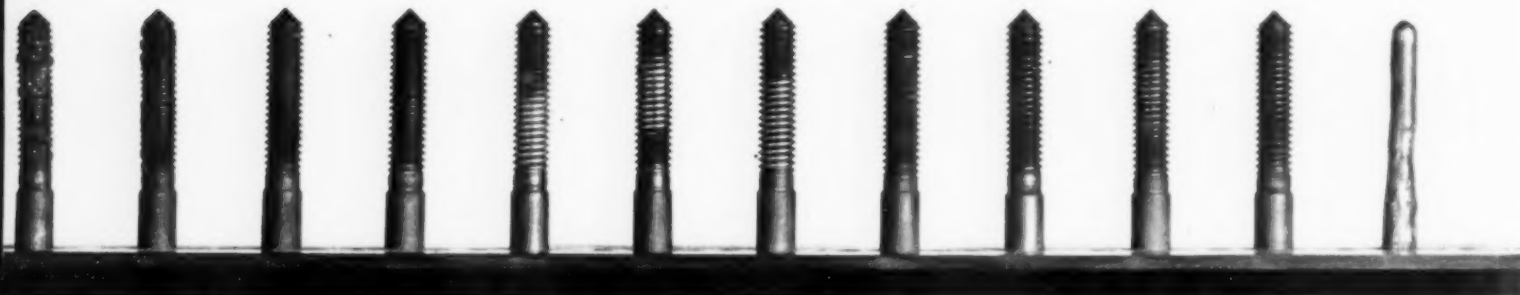
Samples After Filing to Determine Surface Hardness. Series is arranged in order of increasing CO content in furnace atmosphere. Note range of soft pieces midway and piece which melted in high CO

tion corresponding to the 28% point on the diagram, page 77. This method of hardening high speed steel was first used in 1928 by Winter Brothers Co. in Wrentham, and has been successfully introduced since then by the Sentry Co. in several plants in New England.

As used for small taps and dies in the ordinary gas, oil or electric furnace, a carborundum muffle is employed, into which is slipped the diamond block. This block is a specially processed mixture of carbonaceous and other materials, whose composition and manufacture are now being covered by patent applications. The blocks are slotted to receive the tools to be heat treated. A nickel tray is also frequently used, as this permits a number of tools to be hardened at the same time. This nickel tray also prevents direct carburizing of the tools in direct contact with the block. The interaction of the carbon

in different furnaces, and is generally longer in an electric furnace than in a gas or oil furnace. Blocks can be removed when hardening is completed and used any number of times until they are consumed.

Tools can be left at heat in the diamond block for twenty minutes and still remain approximately the same shape and size, so danger of spoilage is greatly reduced.

The gratifying results which are obtained by users of truly neutral gas atmosphere show that difficulties formerly experienced in heat treating high speed steel can be overcome and that proper furnace equipment combined with an understanding and proper application of the correct principles of atmospheric control will enable manufacturers of high speed steel tools to enhance the properties of their products to a gratifying degree.

Standard
Micros
of high carbon steel

By Haakon Styri
and H. O. Walp

SKF Industries
Philadelphia

IN LABORATORIES engaged in metallographic work, a large amount of time is consumed in making photomicrographs. These may accumulate in great numbers, and over a period of years the files are more than likely to contain numerous duplications.

In order to avoid this, as far as possible, the Research Laboratory of the SKF Industries, Inc., has assembled several graded series of photomicrographs, each series covering a certain structural characteristic, such as pearlite, martensite, troostite. The first collection was made in 1921 from photomicrographs then in the files. They were selected so that successive pictures in a series would cover the characteristics in convenient steps. They have been in constant use since they were adopted; the number of photomicrographs selected has been found quite satisfactory, so that comparatively few additions have been found desirable or necessary.

With later developments in lenses and equipment better pictures have been obtained, and some photomicrographs in the first collection have been replaced, and some of the series have been extended as occasion warranted, until the total now numbers about a hundred negatives, filed and classified.

Utility of such a graded classification of structures frequently observed should be more or less obvious. For instance, a group of specimens can be examined and the characteristics of their structures noted in terms of the numbers of the standard photomicrographs. This fixes the structure in the record quite as well as though a fresh negative were exposed. Variations of each characteristic structure can be obtained in condensed form, and such variations can more easily be correlated with physical properties. The use of such a system is thus automatically accompanied by an analysis of the structures.

The photomicrographs in the classification used by us are all of a low alloy steel containing about 1% carbon. The micrographs can be used, however, to represent the structure of plain high-carbon steels and for various alloy steels such as molybdenum or vanadium steel, chromium steel up to at least 3%, and for tungsten and nickel steels where the total alloy content is low.

The prefixed numeral, 1, used throughout,

is to represent structures of steels with about 1% carbon and low alloy content; a similar series on steels of much different analysis will probably be found desirable and should be given a suitable numerical prefix.

Magnifications of 100 and 1,000 diameters only have been used. All pictures at 100 magnifications have been given numbers with one digit (less than 10) and all at 1,000 magnifications, two-digit numbers. It has been found advisable to divide some of the series into groups, each starting with the next higher 10. In the pearlite series, for instance, 1-P-11 to 1-P-14 inclusive form one group, and the next group starts with 1-P-21. This nomenclature may also serve to permit future additions if necessary.

All specimens were etched with 1% nital, and Bausch and Lomb equipment was used exclusively.

In the P or pearlite series, shown on the data sheet page 81, micros 1-P-11 to 1-P-14 inclusive are granular pearlite with different degrees of coarseness of cementite grains. Such completely spheroidized structures can be produced by heating normalized material between $A_{3,2,1}$ (about 750° C. or 1,380° F.) and A_{cm} (about 800° C. or 1,475° F. in this particular steel) and cooling slowly. The time at the annealing temperature, which is usually between 760 and 800° C. (1,400 and 1,475° F.), need only be long enough to effect equilibrium. The size of the resulting cementite grains will depend upon the time and temperature of heating and the rate of cooling. If coarse cementite grains or cementite grain boundaries are present before annealing, then heating to temperatures above A_{cm} followed by rapid cooling is necessary to dissolve and redistribute the cementite completely. No. 1-P-11 (normalized) was held at 790° C. (1,455° F.) for two hours and cooled to 650° C. (1,200° F.) at a rate of about 100° C. (180° F.) per hour, and has a Brinell hardness of 207. Cementite grain size such as 1-P-13 can be obtained by cooling at about 20° C. per hour from 790° C. (36° F. from 1,455°) and has a Brinell hardness of about 180. 1-P-14 will have Brinell hardness of about 154 and was obtained by heating for a long time — 135 hr. — just above $A_{3,2,1}$ and cooling slowly.

Samples 1-P-21 to 1-P-28 inclusive show an increase in quantity and fineness of lamellar pearlite. These can be produced by heating to temperatures in the vicinity of A_{cm} for shorter or longer times followed by more or less rapid cooling. They can also persist after annealing forged or rolled pieces, if the temperature of annealing is too low or the time at temperature too short.

Samples 1-P-31 to 1-P-33 inclusive are in reality a continuation of the preceding group, but contain cementite grain boundaries caused by cooling at a rather rapid rate from above A_{cm}. No. 1-P-31 was taken with oblique illumination, which was necessary to resolve the lamellae in the central grain; with normal illumination this grain appeared like sorbite. No. 1-P-33 could not be resolved into lamellar structure with the optical equipment used.

A cementite or C series, shows the variations in the solution of cementite, and an M or martensite series, representing specimens quenched from increasing temperatures, and tempered to three successively higher temperatures, will be published in a later issue of METAL PROGRESS.

In the T or troostite series, shown in part on page 83, micros 1-T-31 to 1-T-38 inclusive represent different quantities and forms of troostite occurring on the surface, mostly in water quenching. This type of troostite occurs as needles or clusters of needles usually confined to a thin layer, from which it derives the name of "surface troostite." With the same degree of etching, some patches will become quite dark while others will vary to light brown or amber, sometimes almost indistinguishable from the surrounding martensite. We believe it to be caused by a local and temporary insulation existing between hot steel and quenching liquid in the form of a layer of steam.

In the X series are included a few photomicrographs which have not yet been included in regular series, but are of some interest. The troostite in 1-X-21 (shown on page 83) is characteristic of a piece that has been normalized around 900° C. (1,650° F.) and then quenched from about 800° C. (1,475° F.). In form it is much like some of the surface troostite, but it occurs throughout the piece, increasing in quantity from the surface inward. It always etches black.

Properties of Sheet Steel Change With Age

DEARBORN, MICH. — A discussion by E. W. Ehn, in May METAL PROGRESS, of the reasons why low carbon steels change in physical properties with time should be particularly interesting to men in the sheet steel industry. It gives us a clue whereby we may eventually solve the mystery of why some sheets become considerably stiffer after warehousing, or the analogous one of why consecutive shipments destined for the same operation draw quite differently, even though they gave identical results in the usual mill inspection and testing.

Another hypothesis, to which I gave some study when employed as metallurgist for Michigan Steel Corp., is that the phenomenon might be a low temperature manifestation of this well-known fact — that cold rolled steel, when heated to 300 to 500° F., increases in elastic limit and loses elongation. This may possibly be due to recrystallization of the materials along the slip planes of the iron crystals, left in a disorganized condition after the cold work. It is also related to "stretcher-strains," and undoubtedly would have great influence on the ability of a sheet to absorb further deformation, as in subsequent drawing operations. It seems no more than reasonable to assume that effects such as those taking place rapidly on mild reheating will also occur in the same direction slowly, at lower temperatures.

To determine whether this hypothesis could be verified experimentally with the means at our command, we took some sheets of approximately the same composition, one lot hot rolled, normalized and cold rolled (Lot B), and one lot in addition to treatment received by lot B, was box annealed and again cold rolled (Lot A). On both lots sheets were pulled slightly less than 0.5% in final cold rolling.

All test pieces were then prepared, one set from each lot being run at once, and the other sets put aside for the two and six months. All values given in the table below are averages of 12 test pieces.

The grand average of all the tensile tests made in this study is:

	Prompt	Two Months	Six Months
Yield point	26,400	28,300	28,100
Ultimate strength	42,900	44,000	45,400
Elongation: 2 in.	44.3	39.1	40.5
8 in.	27.7	24.7	25.6

Tensile strength and Rockwell hardness are higher after aging, and elongation is less. Erichsen value is lowered, as is also the cup value, but to a less extent. The values after six months aging agree very closely with those at the end of two months — evidently most of the change takes place in a comparatively short time. Presumably the warehouse temperature would have an important bearing on this.

It might also be interesting to note that, while steel made by Treatment A would be graded on the basis of tensile properties as somewhat softer than by Treatment B when made, it had lost most of this margin of ductility within six months.

H. M. COX

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	Prompt Test		Aged 2 Months		Aged 6 Months	
	Treatment A	Treatment B	Treatment A	Treatment B	Treatment A	Treatment B
Rockwell hardness	43	46	47	48	46.5	49.5
Erichsen	11.64	10.88	11.30	10.49	11.25	10.41
Cup	430	396	431	406	425	384
Transverse tensile tests						
Yield point	23,600	26,300	27,000	29,200	27,800	27,300
Ultimate strength	40,800	44,700	43,200	45,500	44,500	44,700
Elongation: 2 in.	45.6	43.3	43.0	39.0	42.0	43.0
8 in.	29.6	27.5	26.4	25.4	28.1	26.5
Longitudinal tensile tests						
Yield point	25,500	27,800	27,500	29,400	28,700	30,200
Ultimate strength	42,500	43,500	44,000	42,900	46,300	46,200
Elongation: 2 in.	44.4	43.5	39.6	36.0	40.3	37.0
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8 in.	27.8	26.6	22.1	23.4	23.0	24.8

Trend Toward Standardization of Aluminum Alloys

TURIN, ITALY — There is at present a rather large number of aluminum alloys normally used in Italy, but there is also a notable tendency to reduce this number. With the gradual improvement of scientific and technical knowledge concerning the alloys, the users have begun to note that the numerous alloys put on the market by the various makers, under more or less extraordinary names, can be reduced to a few typical ones having definite properties and applications. Purchasers are no longer willing to buy what is in reality a more or less standardized alloy simply because it is advertised as being a "special" alloy having new and exceptional qualities. They are studying, and even preparing in their own foundries, the alloys best suited for their individual requirements. Under these circumstances, it is only natural that the greatest part of the "special" alloys have been withdrawn from the market.

Some of the typical alloys whose properties have now been thoroughly studied and which are normally used in Italy are likewise widely used in America. Some others — as far as I know — are not included in ordinary American practice. On the other hand, many alloys of regular American practice are either not used at all in Italy, or only to a very limited extent.

Among the aluminum foundry alloys, the 8% copper alloy (used so generally in America) is one of the more widely used here, especially for automobile and aviation castings, such as housings, crankcases, and brackets. In this field, the aluminum alloys are now being rapidly replaced by magnesium. Another foundry alloy widely used, both in this country and in America, is the "modified" 13% silicon alloy (known as Silumin or Alpax). The alloy containing 5% silicon, generally used in the United States, is not used here, nor are the manganese-aluminum combinations.

For general purposes (and especially for heat treated die castings) an alloy is widely used in Italy known under the commercial name Anticorodal. It contains about 1% Si, 0.6% Mn, and 0.6% Mg. As far as I know, castings of this approximate composition are not used in America for the same purposes. Two alloys are generally used in Italy for the manufacture of pistons for internal combustion motors: The first contains 12% copper, and the second (which is especially suitable for heat treating) 13% copper in addition to magnesium, iron, and manganese.

Alloys regularly used in Italy for plastic working, such as rolling, forging, stamping, and extruding, can be divided into three groups:

The first group is characterized by the constituent Mg_2Si, and includes all the alloys suitable for overhead electric transmission lines. The most generally used is Aldrei. To the same group belongs the above-mentioned Anticorodal. As far as I know, this alloy should be similar to the American alloy 51-S, the only difference being the content of 0.6% manganese. It is used here in all places where resistance to corrosion must be taken into consideration in addition to good physical properties. As the strength of this alloy is only a little below that of normal duralumin, while its cost is lower, it is much used for chemical apparatus which is subject to mechanical strain, and also for parts of streetcars and heavy motor trucks. On account of its remarkable silvery color, it is also used for attractive architectural decorations.
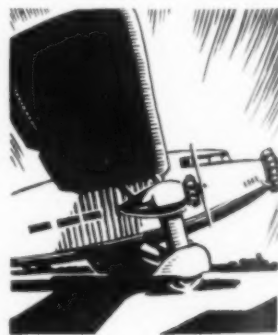
The second group, characterized by the constituent $CuAl_2$, includes many alloys. The most commonly used is known in Italy as Lautal, and is very similar to the American alloy 25-S. It is used here wherever high physical properties are more important than resistance to corrosion.

Among the alloys of the third group — which might be called the duralumin group, characterized by both constituents Mg.Si and CuAl, — the most generally used in Italy are known by the commercial names Avional and Aldal. They are not very different from the alloy 17-S, manufactured by the Aluminum Co. of America.

In addition to the alloys belonging to the three groups above quoted, sheets and shapes of a German aluminum alloy, called K. S. See-wasser, are finding very wide applications (especially in naval construction). I believe this does not correspond to any of the alloys used in America. It has a great resistance to corrosion, especially in sea-water. Furthermore, the applications of bi-metallic sheets having a Lautal core covered by thin layers of highly purified aluminum are rapidly expanding, as can also be noted for the corresponding substance Alclad in America.

FEDERICO GIOLITTI

Steels Hardened Magnetically To 1,000 Brinell

SHEFFIELD, ENGLAND — At the autumn meeting of the Iron and Steel Institute two years ago great interest was aroused by a paper by E. G. Herbert on the increase of hardness of cold-worked steel by applying alternating magnetic fields. The author is well known on account of several ingenious experimental methods which he has introduced into metallurgy. Prominent among these are his pendulum hardness tester, which allows the work-hardening capacity of a metal to be determined as well as its intrinsic hardness, and his "cloud-burst" process for superficially hardening a metal by allowing a shower of small steel balls to fall on it.

It was next shown that after a steel object had been super-hardened by the cloud-burst process its hardness could be still further increased by annealing at a low temperature, such

as 120° C. In view of previous knowledge, this was not surprising, but it was distinctly surprising to learn that the same effect could be produced by placing the hardened surface on a large electromagnet, tapping lightly with a hammer, turning the specimen through an angle and repeating the process a number of times.

The author has followed up these experiments, and the results appear in a paper communicated to the Royal Society of London. As an example, the behaviour of a specimen of high speed tool steel may be taken. This was quenched from 1,300° C. (2,375° F.) and the hardness of Brinell 700 was found to increase rapidly by aging, a stable value being obtained after two hours. It was then slowly revolved in a magnetic field of about 14,500 gauss at the temperature of boiling water, with the result that the hardness fell for a few minutes and then rapidly increased. After three hours a stable high value was obtained. The specimen was then surface hardened by the cloud-burst method, aging for three hours giving a greatly increased hardness. A repetition of the magnetic treatment again produced a slight but rapid softening, followed by an increase of Brinell hardness to 1,000, well above its original value.

Exactly similar changes were observed in a high carbon steel; the Brinell value of 715 after the first quenching was increased to the final aged and magnetically treated condition of 1,080. When several magnetic treatments are applied in succession with intervals between, curiously complicated changes in the hardness are observed. A few revolutions in the magnetic field appear to be as effective as a larger number.

So far it might be possible to explain the effects as connected with magneto-striction, which may bring about considerable distortion of the space lattice of a magnetic metal, but the explanation is made much less obvious by the observation that even non-magnetic metals may be affected in a similar manner. Slowly turning a specimen of quenched duralumin in a magnetic field accelerates the process of aging, the hardness attained in 12 hr. being as great as

that normally reached in 34 hr. Even brass shows periodic changes of hardness when subjected to magnetic treatment, although its final hardness is not increased.

The effect on mild steel is remarkable. A single rotation in the strong magnetic field at room temperature will produce, after an interval of eight hours, a maximum hardness corresponding to an increase in tensile strength of 20%. It is clear that the discovery may have important practical applications, and that much further work will be needed before it can be fully explained.

CECIL H. DESCH

Endurance of Steel Depends on Structure, Strength and Ductility

STOCKHOLM, SWEDEN — For a number of years A. Lundgren of the Swedish Government Testing Institute has carried out investigations on the fatigue limits of steels, and he recently published his results, which are of considerable interest. The testing machine employed was the Swedish "Alpha" machine, for rotating specimens.

Lundgren has given considerable attention to the relation between the endurance limit and other mechanical properties of the steels investigated. No marked relation was found between the fatigue limit and the limit of proportionality or the yield point. On the other hand the relation between the endurance and the ultimate stress seems to be better defined. To support this conclusion Lundgren used not only his own results, but also made a compilation from most previous investigators in this field.

The ratio K between fatigue limit and ultimate stress was found to vary within certain limits for a given class of steels, and to increase with increasing ductility as measured by reduction of area in the tension test. In plain carbon steels with pearlitic structure the value of K was found to be about 0.37 when the reduction of area was less than 36%. Pearlitic nickel and chromium steels give higher values of K than the plain carbon steels.

In quenched and tempered steels with sorbitic structure the value of K is considerably higher than for pearlitic steels. While the value K = 0.39 was found in a pearlitic steel with a reduction of area of 40%, the corresponding value in a sorbitic material was found to be K = 0.58. In the sorbitic steels the increase of K with the reduction of area is not so pronounced as in the pearlitic steels.

Quenched and tempered steels with a relatively low content of carbon and consisting of a mixture of ferrite, sorbite and pearlite (with the ferrite to a large extent in the form of a network) show considerably lower values of K than the sorbitic steels, and sometimes even lower than the pearlitic steels.

Quenched steels, finally, with a martensitic-troostitic structure and high ultimate stress give lower values of K than the sorbitic steels.

By investigating steels heat treated in different ways it was further found that widely differing annealing temperatures had a very slight influence on the fatigue limit. On the other hand the endurance is considerably increased by quenching and varies with the degree of tempering.

Lundgren further investigated the influence of different forms of the test piece and of different ways of carrying out the test. The radius of the fillet between the head and the cylindrical part of the test piece was found to have a considerable influence on the endurance. Test bars for cantilever loading were made with a radius of fillet of 0, 1, 2, 5 and 10 mm. A radius of 10 mm. gave a 90% higher fatigue limit than a radius of 0 mm., and 2% higher than a radius of 5 mm.

The number of rotations after which the fatigue curve becomes asymptotic was also investigated. Lundgren found between 1,000,000 and 2,000,000 rotations for two normalized carbon steels and less than 1,000,000 for a sorbitic chromium-nickel steel.

EINAR ÖHMAN

Three Overlapping Reactions Occur During Tempering

PARIS, FRANCE — There are few problems which have instigated more or deeper researches than the reactions taking place during the tempering of hardened steels. Even so, no coherent theory exists which is universally accepted.

Some experimenters have postulated phases or components in addition to those originally proposed by Osmond in order to interpret the phenomena and the resulting modifications of properties. It would seem, however, that a fundamental error of most of the research programs was to assume that it is possible to obtain pure martensite, and that a micrographical study (or a hardness measurement) would be sufficient to determine whether this component were or were not mixed with the others (especially austenite). Moreover, researchers often were content to study one or two characteristics of the metal, too few to define accurately its state, its components, and consequently the phenomena which produced the conditions under examination. With a multiplicity of possible reactions, one must utilize a number of physical properties and distinctive characteristics to fix his ideas.

Lastly, it must not be forgotten that the carbon concentration in the gamma solid solution (or austenite) is not uniform, as is proved by the persistence, through all thermal treatments, of the macrographical appearances developed by the cupro reagents. The same is true of the alpha solution (or martensite) which is derived from it. Even if we suppose the generating austenite to be homogeneous, the production of martensite necessarily involves an irregularity in the phase concentrations which cannot entirely disappear by means of diffusion in the solid state, because of the low temperature and of the rapidity of the transformation.

For these reasons M. Chevenard and the writer studied minutely and completely the tempering of hardened steels under the following conditions:

First, we began with the study of austenite. This is the only component of quenched or tempered steel that can be obtained in a pure state. It will be observed that this is just the reverse of the position taken by most of the other experimenters—they began with the study of martensitic specimens, erroneously considered as being "pure," that is, of that phase exclusively.

In the next place, we determined a number of physical and micrographical properties of the phases austenite, cementite, martensite, and ferrite, rather than relying solely upon their micrographical appearance (which is a source of many mistakes).

Third, we studied simultaneously a group of these properties characterizing the components and their transformations, such as the coefficient of expansion, the temperature and the amplitude of thermal transformations and of the cementite anomaly, the variations in hardness, resistivity, residual magnetism, and coercive force.

Last, we studied the conditions within the steel when it was held at a constant temperature. Curves showing the relation of length of specimen with time, for instance, were drawn with automatic devices. Interpretation of these curves clearly showed the overlap and coexistence of reactions. The most important conclusions of this long study are as follows:
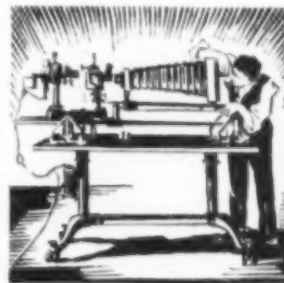
All the phenomena observed during the tempering of hyper-eutectoid austenite can be explained by three elementary reactions, often superimposed and entangled:

I. Decomposition of supersaturated austenite (gamma solution) into cementite and a saturated austenite.

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Stretcher Strains

depend upon speed of draw

ONE OF THE GREATEST difficulties encountered in the forming of sheet and strip steel by the deep drawing process is the occurrence of "stretcher strains" on the surfaces of the metal after the draw has been completed.

Stretcher strains (or more appropriately "worms") are the shop names for the phenomenon known as the "Lines of Lüder," after Lüder of Magdeburg, who first described them in 1860. These lines appear on the metal after drawing as irregular lines of depressions or elevations which destroy the evenness of the surface. If the stresses producing the deformation are primarily tensile, the lines appear as depressions

in the surface; if the stresses are primarily compressive, irregular lines of elevations occur. They tend to occur in those stampings or parts of stampings in which the elongation in forming is between 1.5 and 10.0%. Sometimes these markings are so extensive, as in the photograph reproduced above, that it is necessary to grind and polish the entire surface of the stamping. Even this is not always accomplished satisfactorily because the heat produced by these operations tends to cause severe distortions.

In a paper presented before the American Society for Steel Treating in February 1930 by Winlock and Kelley entitled "Sheet Steel and

Strip Steel for Automobile Bodies," with one of the present authors as co-author, stretcher strains were described as being due to the fluctuations occurring at the yield point.

Occur at Yield Point

These are shown on the full line in the stress-strain diagram on page 92, and are caused by the transitions in different grains or groups of grains from the elastic to the semi-plastic state. These steps can produce severe surface markings only in those metals in which this transition is relatively abrupt. It was pointed out that the surface markings decreased in magnitude as the load (produced by the increasing deformation) increased, until the effect of contrast was so diminished as to effect a return to the original even surface. It was shown that by properly regulating the amount of cold work performed on the steel prior to the deep drawing operation, the stress-strain diagram could be made relatively smooth from origin to fracture, as shown by the dotted line in the sketch. Such treatment prevents the occurrence of stretcher strains in the stampings, provided, of course, that before the deep drawing operation there has not been time enough for the return of elasticity ("aging") to take place.

In an attempt to throw some further light on Lüder line formation, we have just completed a few experiments which, although preliminary, nevertheless gave such interesting results that we felt it might not be out of place to report them at this time.

Tensile specimens were machined from a sheet of strip steel 0.037 in. thick by 36 in. wide by 97 in. long. It had been made according to regular mill practice, that is, it was hot rolled from a slab to about 0.060 in. in thickness, annealed, reduced by cold rolling to 0.037 in., and finally box-annealed at 1,400° F. (760° C.). The specimens were taken both longitudinal and transverse to the direction of rolling. They were 0.750 in. wide and the gage length used was 8 in.

Specimens were divided into two lots. One lot was for testing without further treatment and is called the box-annealed group. One lot was to be heated before testing to above the Ac_3 point of the steel. The latter, or normalized

group, were carefully sealed in pipes to prevent scaling, placed in a furnace which had been heated to 1,750° F. (950° C.), held for three hours, and then drawn from the furnace and allowed to cool in the air.

Chemical analysis of the steel was: Carbon, 0.06%; manganese, 0.36%; phosphorus, less than 0.015%; and sulphur, 0.030%.

Percentage elongation in 8 in. in both groups when tested in the usual manner (at a rate of deformation of 2 in. per min.) was approximately the same; namely, 31%. Both groups of specimens were then pulled at the following rates of deformation: 2, 9.5, 10, 11.5, 16, 18, 19, 22, 39, 60, 96, 102, 126, 156, and 252 in. per min.

In pulling the box-annealed specimens it was found that when the rate of deformation increased to 19 in. per min. the irregular lines of depressions did not "widen" and "disappear" in every test piece, but fracture occurred before parts of the specimen had permanently elongated. An average of four longitudinal and four transverse specimens were pulled at each rate of deformation, and premature fracture occurred in at least five out of each eight tests when the rate of deformation exceeded 19 in. per min. When premature fracture occurred, the percentage elongation in 8 in. was, of course, very low because only parts of the specimen had elongated. Photographs show two specimens which fractured in this manner and a close-up of a portion of such a specimen.

As before noted, normalized specimens were also pulled with the same rates of deformation. Stretcher strains formed as usual, but these always "widened" and "disappeared" as the deformation increased. In no specimen

Full Size View of Portion of Test Piece (Such As Illustrated on Next Page) Located Some Distance From Fracture
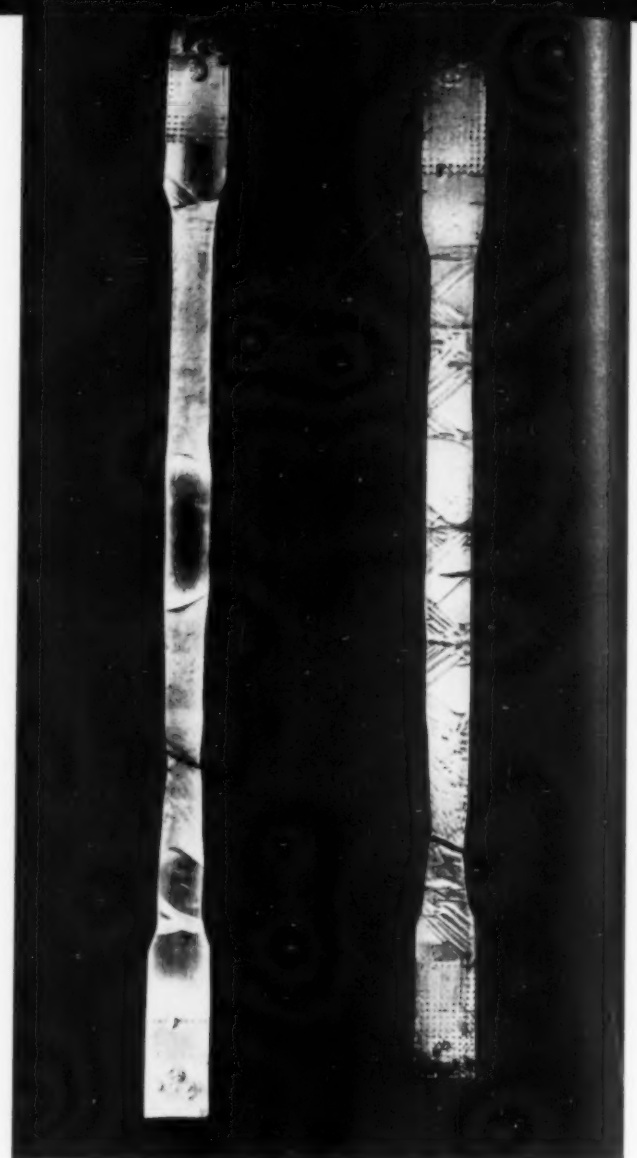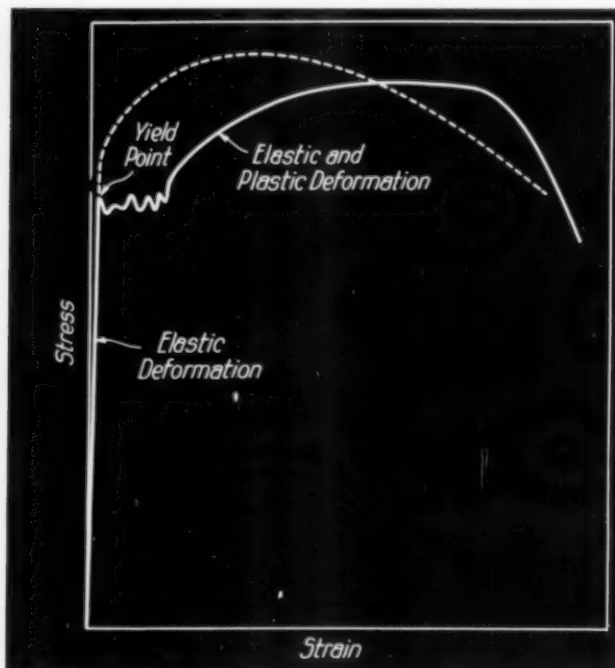
did premature fracture occur during the test.

Specimens of the box-annealed steel were then pulled at the rate of 2 in. per min. until all the large depressions had "appeared" and "disappeared." An elongation of 10.0% was necessary to do this. The test pieces were then immediately (so that very little aging could occur meanwhile) elongated to fracture at 252 in. per min., a speed which would have yielded a low percentage elongation and would have left portions of the steel unstretched had this speed been used alone. It was found that by first stretching at slow speed followed immediately by the faster speed, the detrimental effects of the fast rate of deformation were removed; premature fracture did not occur in any such sample.

Without attempting to explain the underlying causes, a brief discussion is offered of some of the results obtained.

Permanent deformation of steel takes place by the alternate slipping and work-strengthening of the different grains or groups of grains. When the load induced by the deformation reaches the yield point of the steel, the resistance to permanent deformation is overcome and slip

Typical Tensile Specimens Which Developed Markings Over the Entire Length and Then Failed by Localized Elongation

Abrupt Transition in Various Grains From Elastic to Semi-Plastic State Cause Fluctuations at Yield Point Which Are Absent In Cold Worked Material (Dotted Line)

commences. The intensity of the stress on the first grains to yield is increased by virtue of the reduction in cross-sectional area, but due to work-strengthening, the resistance to further slip is also increased. The result is that the actual load-carrying capacity of the permanently deformed grains becomes greater than that of their neighbors which have been only elastically deformed (or semi-plastically when the extension has become greater).

It is obviously fortunate that this is so, otherwise steel could not be formed by the deep drawing process, because if the metal behaved as a perfectly plastic material, the slightest concentration of the imposed stress (caused perhaps by the shape of the finished article) would cause fracture to take place. Pitch, for example, could not be drawn because no work-strengthening would take place at the point at which the cross-sectional area is first reduced.

Fracture would result almost immediately. In order to deep draw a perfectly plastic material it would be necessary to have (a) a perfectly homogeneous substance, and (b) an absolutely uniform distribution of the stress — two conditions which would be very difficult, if not impossible, to obtain.

In the ordinary tensile test, the rate of deformation of the specimen as a whole is constant while the load varies according to the resistance to deformation set up by the steel. Stress-strain diagrams obtained under these conditions show only the average conditions existing beyond the yield point — that is, the average elongation and the actual total loads induced by the deformation. Thus, if after only a portion of the specimen has slipped, the gage length were to be shortened so that only this portion of the specimen is included, the stress-strain curve would be found to be rising as a comparatively smooth curve. This small gage length usually does not in itself show any severe surface markings. If, however, the longer gage length is considered, it is found that a difference in level exists between the portions which have slipped and those which have not slipped. It is the effect of this contrast which produces the severe surface markings.

We do not mean to infer that the small gage length does not also show some markings, but we find that these are usually so small as to be almost indistinguishable. Contrast is a question of degree and not kind.

The actual increase in resistance to slip, resulting from the permanent deformation of steel, is, however, not only dependent upon the amount of permanent deformation and the temperature at which it is performed, but also upon the time in which the deformation is produced.

By pulling the box-annealed specimens slower than 19 in. per min., permanent deformation took place at a rate slow enough to produce enough work-strengthening so that other parts of the specimen were forced to elongate also. But when a higher rate of deformation was employed there was not time enough for sufficient work-strengthening to take place. As a result of this, premature fracture occurred.

The time necessary to prevent premature fracture appears to vary according to the heat treatment and other conditions existing in the
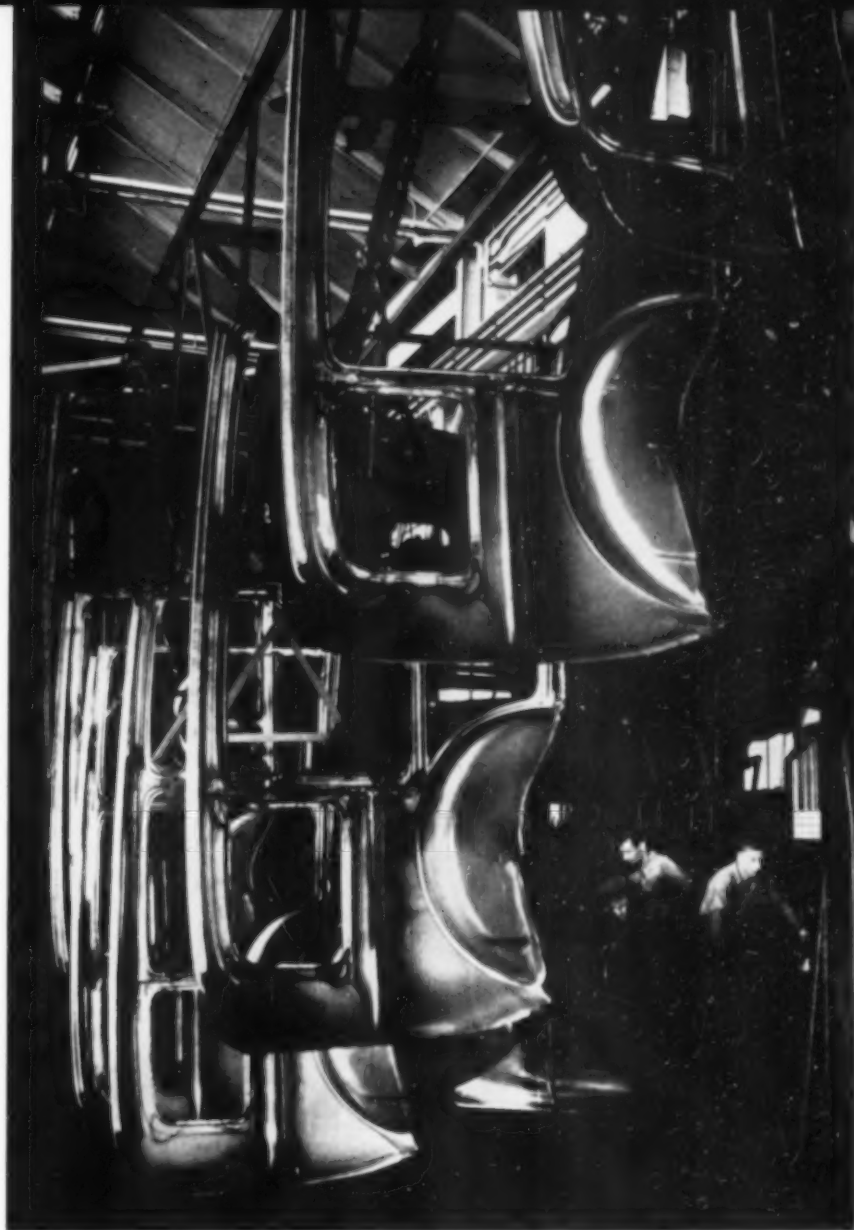
A Conveyor Line at Edward G. Budd Mfg. Co.

steel. This is shown by the fact that the specimens heated above the Ac_3 point of the steel could be pulled at any rate between 2 and 252 in. per min. without prematurely fracturing.

The time necessary for sufficient work-strengthening to take place to prevent premature fracture from occurring seems to decrease as the extension increases. This is shown by the fact that the box-annealed specimens when pulled first with a slow rate of deformation followed by a faster rate elongated without fracturing prematurely.

It would seem, then, that low carbon steel is best suited for deep drawing purposes when it is in the semi-plastic condition, since it can then be deformed at a faster rate without premature fracture taking place, and no stretcher strains will form.

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Statistical Control

how new science promotes uniformity of product

IT MAY BE SHOWN that the real value of all scientific knowledge resides in the possibility which it provides for the prediction of future phenomena from a knowledge of past performance in a given environment. Ability to predict future phenomena also depends upon the degree to which certain measured quantities are reproducible. Furthermore, the reproducibility of a measured quantity usually is dependent upon two sources of variation, of which the latter is of more general interest: First, the accuracy with which the measurement can be made, and second, the extent to which all causes contributing to the variation of the quantity can be controlled.

In most measurements, we consider that an uncertainty of 1 part in 10,000 constitutes a highly satisfactory degree of reproducibility in the measured quantity. The value for the velocity of light, 2.9986 x 10¹⁰ cm. per sec., has a stated uncertainty of 0.0003. This is very nearly 1 part in 10,000. Proceeding toward the other extreme, the ductility of a metal test specimen is considered satisfactorily measured if a reproducibility of 1 part in 25 is obtained. The tensile strength of cotton fiber from a given lot will vary considerably more. The life spans of individuals are even more variable. It is because of the lack of reproducibility of a given quantity that modern methods of statistical analysis are becoming of such great importance.

If Dr. Michaelson were to have made a large number of measurements of the velocity of light, he would have found a variation of ± 25 miles per sec. as extremes in any properly made set of experiments. Had he plotted a frequency curve, he would have found a distribution of values similar to one of the curves shown on this page.

How do we know that the velocity of light

Normal Distribution of Values About a Mean. Standard deviation ranges from quite large for the flat curves to rather small for the thin curves.
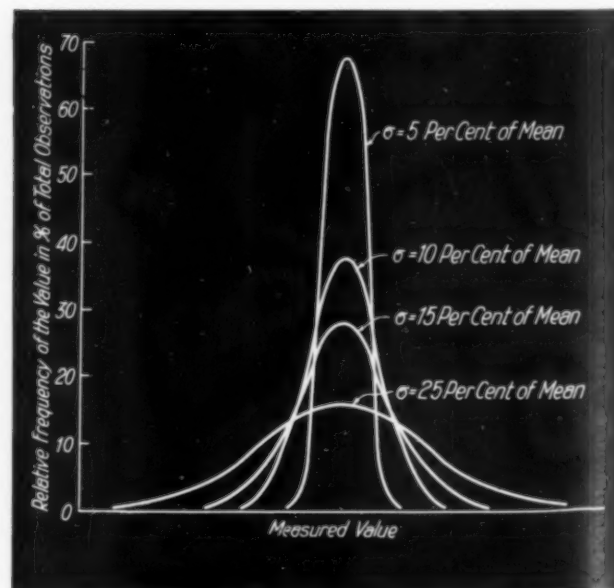
is constant? Because the average of our best measurements is as close as 1 part in 10,000. We therefore set up a functional relation between the three quantities, distance, velocity, and time, and the value of this relation lies in the fact that its validity enables us to predict distance to such accuracies as 1 part in 10,000.

In other words, this scientific knowledge enables us to predict the distance of astronomical bodies.

A problem nearer to the interest of readers of METAL PROGRESS would arise in an attempt to predict the tensile strength of a test sample taken from a casting produced by a given process. The problem then takes on a less satisfactory form. If the strength could be predicted, there would not be the need to cut so many test bars and verify the prediction. Then the process would be under correct control, and this article will attempt to indicate how the science of statistics will aid in establishing such control.

In the first place, one could expect a variation in the measured values of test bars from the same lot of metal, and also a variation from different lots of material produced by the same processing method. Can these variations be prevented? Should they be accepted as the result of chance?

The ever-present distribution of values about a mean, and the variation in the breadth of the distribution, are illustrated in the first figure. For the sake of convenience, these frequency curves are drawn to conform to what is known as "the normal law." They can be expressed mathematically, and the width of their dispersion is measured by the "standard deviation" σ.

There are other reasons for choosing the normal law for illustrative purposes, one of which is that it happens to be the one which represents the conditions of maximum control. It is also used because the distribution of averages of samples of size 4 or 5 (small groups of 4 or 5 observations) is very nearly normal, although the "universe" from which they came may differ considerably from the normal. Consequently, it can be used most conveniently to give a non-mathematical view of the more important features of statistical control.

Although the family of curves are all nor-
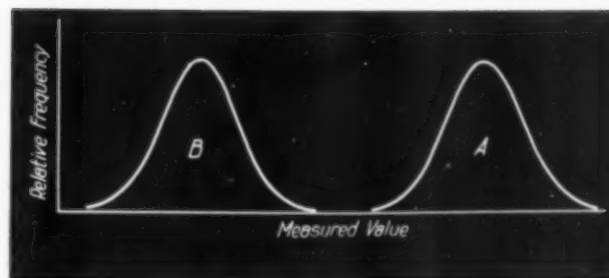
If a Compilation of Data Is Influenced by a Large Effect, in Comparison With the Number of Circumstances Which Have Minor Effect and Produce a Normal Distribution Curve, Then the Distribution Curve Will Prove to Have Two Nodes

mal, yet they differ widely in the value of the standard deviation, σ. The flatter the curve the larger the value of the standard deviation. While it is desirable to have the standard deviation as small as possible, yet from the standpoint of prediction of future behavior from that of the past, a much more important characteristic is the knowledge whether or not *all* of the values come from a single universe, or, in other words, are the result of the same set of chance causes.

The second figure shows frequency curves for two groups of data (two "universes") which are normal and which have the same standard deviation, but which differ in the mean value for the measured quantity. While the distribution of individual measured values about the mean in either of the universes is due to a considerable number of minor causes, the position of the two mean values indicates that there is one cause, or one group of causes of comparatively large effect, which is responsible for the separation. The fact that the two universes have the normal form and essentially the same standard deviation indicates that in both universes the same minor or chance causes are operating with the same probabilities.

For purposes of prediction, the form of the distribution curve is not so important as is the fact that within each set of values the number of causes, their magnitude, and their probabilities of action do not change. If, however, there is present in such a system one cause whose effect is large compared to the other small causes, the plotted data may show a distorted or lopsided distribution curve, or a distribu-

tion about two mean values such as are illustrated. Prediction from such a system can only be made when the two universes are considered individually or when this predominating cause has been eliminated.

Now, if the number of causes of variation is constant, if the effect of each cause when in action is constant, and if the probability of each cause acting is constant — then the data coming from such a system will vary in a definite way. It is quite likely that the distribution of values will approximate the requirements of the normal law; certainly if each 4 or 5 observations are averaged and the averages studied the latter will approach the normal distribution more exactly.

In order to predict with any degree of assurance, it is necessary to know that any environment is a "constant system of chance causes," that is, that the causes are constant in number and effect and with constant probabilities of action. At this point, modern statistical theory enters the problem.

The older approach to the investigation of data was to find the form of distribution which the data took. Behavior of that system in the future would then be assumed to be the same as that represented by the data already at hand. Modern statistical theory has presented a more definite solution in the form of a number of criteria, whose purpose is to determine whether or not the data have come from a "constant system of chance causes." It is not the intention of this discussion to go into the details of the technique for discovering assignable causes of variation. However, it is the intention to emphasize that the essential requirement of data which can be used for prediction is that the system of causes is constant. This criterion may be determined simply, as follows:

It can be shown that the area of the normal universe which lies between the limits of the mean plus and minus 3 times the standard deviation, is 99.73% of the total area of the curve. If these limits are fixed, the probability that observations will fall between these two limits is constant and equal to 0.9973. It is not possible to say that *all* observed values will remain forever between these limits (since the probability is less than unity), but the acceptance of this concept of variation within specific
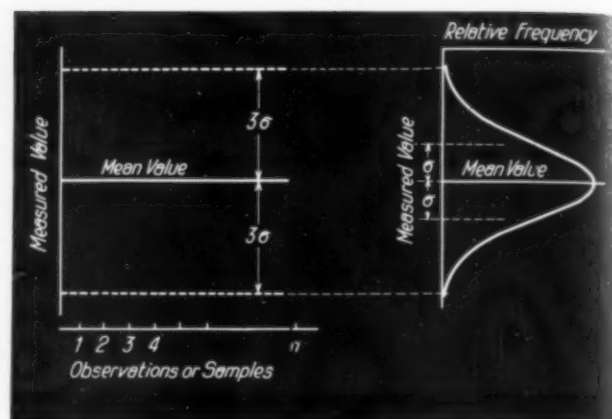
99.73% of the Observations Comprising a Normal Universe Fall Within the Limits of Plus or Minus Three Times the Standard Deviation. If some observations in a certain series fall outside these limits, there is some uncontrolled variable which influences the results

limits does not lie in the theory which developed it — its justification is found in the empirical fact that it works.

A specific instance of the use of this criterion will now be given.

In the production of a certain kind of telephone equipment, the necessary electrical insulation was very costly. After a long preliminary search for a cheaper material, a tentative substitute was chosen and an extensive series of resistance measurements was made on it. In one study, 204 such observations of resistance were grouped in fours, and the average of each "sample of size 4" plotted in the figure on page 97. The mean value and the standard deviation for this series of experiments were also computed and used in plotting on the diagram. It will be noted that a certain number of values lies beyond the limits, which are the mean plus or minus 3 times the standard deviation.

According to the criterion, therefore, one or more causes of variation existed which were not constant in effect or probability of action.

Further research was then instituted to find the causes of this excessive variation. Several of these were found and eliminated. Then another set of observed values was taken, computed, and plotted as indicated at the right of the same figure. Here, all the points are seen to lie within the limits, $\pm 3\sigma$. The manu-

facturing technique was then judged to be under control.

Because of the importance of this particular operation, considerably more work was done, but it failed to reveal additional causes of variation. It is therefore a typical case which shows the type of data that can and cannot be used for prediction. No assurance could be had of predictions conjectured from data of the type shown at the left of the figure, while reliance could be placed on the data at the right.

Obviously, if one desired to make a casting whose ductility is of importance, it would be desirable to have the deviation from one casting to another as small as possible. However, it is more desirable from the standpoint of prediction to know that the values of ductility are controlled and defined by a constant system of chance causes, and that the larger or assignable causes of variation have been removed.

Returning to the second figure, it is possible for one familiar with the source of the data plotted to think of an assignable cause of variation as the cause which separated the two distribution curves. Suppose it to be eliminated; then the last control chart shown in this article represents at the left the resulting data from

the universe A; they would fall between the limits shown by the dotted lines. Similarly, if the experimental data had all been taken with the assignable cause of variation operating continuously, all values would again be controlled and lie about the mean for universe B, and between the limits established for it. On the other hand, if observations were being made when the assignable cause of variation was operating part of the time, it is very likely that *some* of the values would lie within the limits of control, but many values would be above the upper limit and some below the lower limit. If the assignable cause operated 50% of the time, the mean would lie in a half-way position shown in the figure, but all values would be found outside the limits.

The power of this criterion can only be indicated in these few paragraphs. The success of its application depends to some extent on the manner in which the observations are grouped into samples. If two identical units — furnaces, perhaps — are handling the same kind of product, it is most natural to consider the data from each unit separately. Similarly, it is logical to take the pieces in the order in which they are finished from one machine; the subgroups (or samples) should be small in size so that the operating conditions are nearly constant while each sample is being made.

If by accident or intent, each sample is composed of observations made under different conditions (that is, the data from the two universes are scrambled within each subgroup), it is likely that an assignable cause of variation will be overlooked even though one exists. The standard deviation of such a mixed system will then be large and the limits of control will be quite wide as shown at the right of the last figure. When data are collected in such a way, the effectiveness of the method is lost.

A Series of 204 Observations on Electric Resistance of a Newly Developed Insulation Was First Averaged in Groups of Four and the 51 Results Plotted. Several were found to be beyond the allowable limits. When several manufacturing details were brought under control, the "scatter" was correspondingly reduced

A Manufacturing Illustration

To illustrate in a more concrete manner, it is well to consider broadly
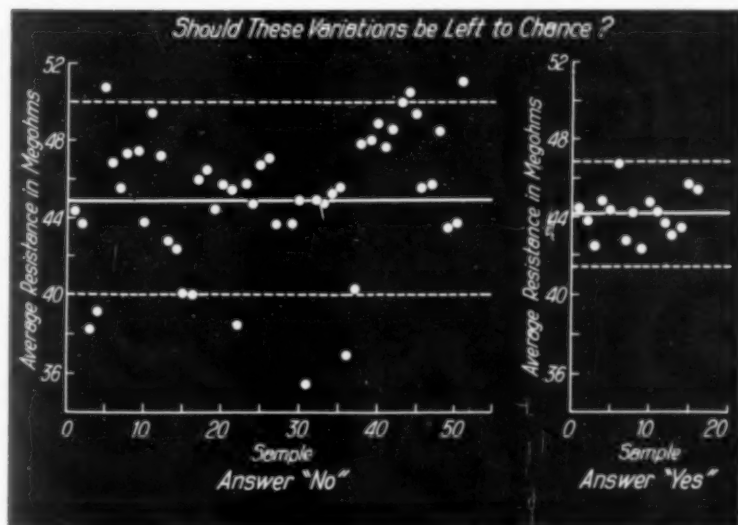
the significance of these methods as related to the production and improvement of a controlled product. For this purpose, consider the process of manufacturing a certain type of malleable iron casting, consisting of the following steps:

1. Raw materials, namely, pig iron, steel, and cast iron scrap.
2. Melting process.
3. Foundry practice, such as design of mold and condition of sand.
4. Cleaning of the white iron castings.
5. Annealing of the castings.
6. Cleaning of the annealed castings.

When the castings are produced in one plant, a rational grouping of data to determine the effect of certain variables in each step of the process consists of the measurement of some property or group of properties resulting from each step in the process, and which may be expected to be most closely related to the property of the finished product in which we are interested. Assume, for example, that we want high and uniform tensile strength and ductility. In the raw materials, chemical composition would be expected to be one of the important factors, as well as the source and the previous history of these materials. In the melting practice, there are a great number of variables which might be effective, such as initial composition of charge, rate of melting, rate of change of composition of the bath during the melting time, temperature of tapping, and length of time of pouring. By standardizing over a series of heats on a set of conditions with respect to all these conditions, a controlled casting might be expected as far as influences of melting conditions are concerned.

Influences on Melting Conditions

In the molding process, the nature of the molding sand, its moisture content, and the temperature of pouring, should be considered as possible influences.

In the annealing process, the factors which make up the annealing cycle should be controlled, as should also the conditions for decarburization and oxidation.

The matter of cleaning of castings, both the white and the annealed, would not be considered because it is doubtless of minor importance as related to the uniformity of the tensile strength and the ductility.

If the chemical composition of the raw materials and the sources from which they are obtained are maintained (within as close limits as possible); if the chemical composition of the metal coming from the melting furnace and the conditions under which the melting is carried out are carefully regulated; if the conditions around the pouring of the castings, such as the porosity of the molding sand, its moisture content, the rate and temperature at which the metal is poured are uniform;
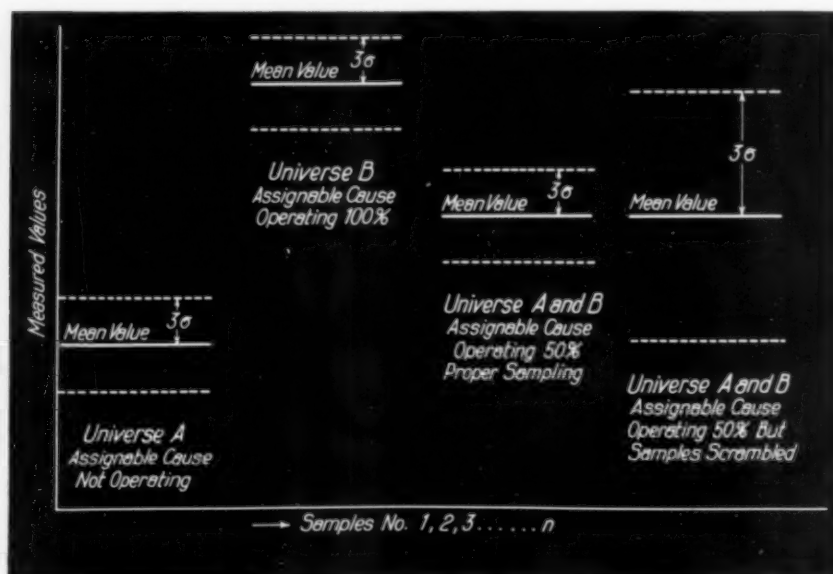
Location of Mean Value and Allowable Scatter of Observations From Universe A and Universe B, When Assignable Causes Are or Are Not Operating, and When Samples Are Either Separated or Scrambled

and finally if the annealing cycle and the atmospheric conditions determining decarburization and oxidation are kept within close limits — a controlled product in terms of tensile strength and ductility of a casting of a certain design might be hoped for.

The method of testing for a statistically controlled product consists in measuring the tensile properties and ductilities of certain small groups of castings (samples) from each heat of castings and over a considerable period of time. The results of the tensile properties of such samples are plotted against time on a control chart similar to that shown in the figure on page 97.

If the data fall within the limits required by such a chart for a considerable portion of time, and over a considerable number of heats, this circumstance would indicate a statistically controlled product. However, one would be extremely fortunate should statistical control be discovered after such an initial attempt, and particularly should it be maintained over any considerable number of heats. The question as to what could be done to discover assignable causes for variation, in the event such an initial attempt proved unsuccessful, requires real ingenuity on the part of the investigator.

If tests are available on the product from each step, then the process of obtaining control would consist of examining the data for evidences of control after each important step in the processing. If such tests cannot be made, the search for the assignable causes of variation becomes much more difficult.

Variables Must Be Studied

It most frequently occurs that an uncontrolled product is obtained after the initial attempt to control the process of manufacture. This may even happen after a number of repetitions of the attempt. Each such failure indicates that a closer search of one or more of the manufacturing steps is required. This phase of the search is in no way aided by statistics except that the criteria show the presence of assignable causes of variation. The most essential feature of the search is the use of "good sound common sense" in selecting such variables as may prove to be the cause of variation outside the limits required for statistical control.

One must select possible new causes of variation and repeat the experiment; this represents the method of attempting to obtain a controlled product. Obtaining control of a product as difficult to regulate as a malleable casting may require laboratory explorations of the effects of possible causes of variation. However, the process finally resolves itself into that of proving, in the plant, that statistical control of the quality of the product has been obtained.

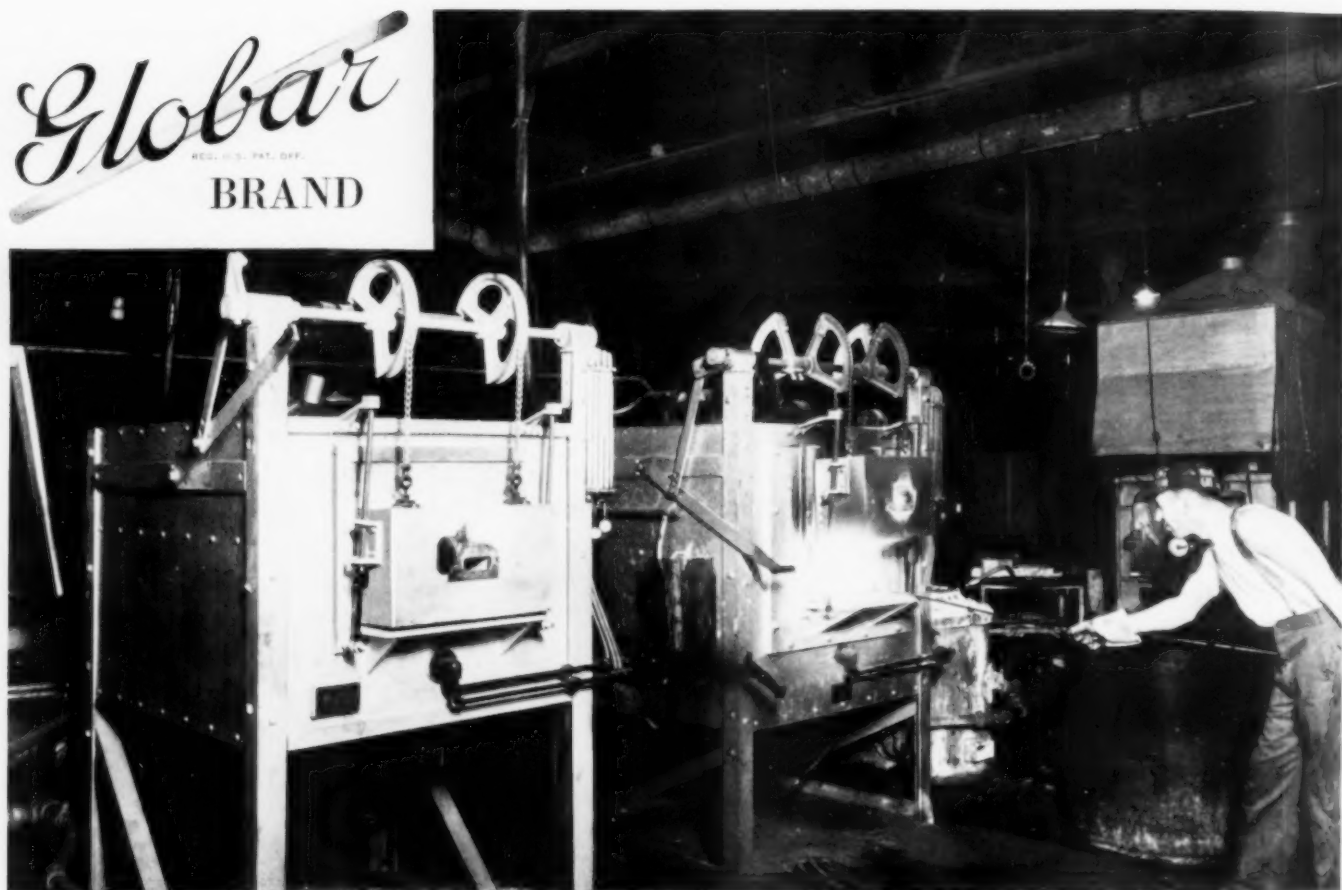## Opportunities in Statistical Control

When statistical control in the plant has been accomplished, there exists an opportunity — which can be expected to be of great value — to use the operating facilities to investigate the effects of certain variables on the quality of a product. Once it is shown that the process of manufacturing has produced and is producing controlled quality of the properties of the finished product, the production unit immediately becomes a powerful research facility so long as these conditions are maintained. It is then possible to vary any single chosen factor at will and determine the influence of such a variable on the quality of the product.

Many, even in some of the best research circles, have disregarded the assistance which modern statistics can give. The new methods are being rapidly developed. They open up a scientific approach to the use of data for purposes of prediction, which were formerly considered entirely empirical, and have already removed any excuse for the frequent statement that "anything can be proved by statistics."

The limits for the range of quality of a product and the probability of its falling within these limits are definitely predictable if the data are shown to be the result of a constant chance cause system. The universal applicability of the methods to the examination of data, whether it be for purposes of prediction, of uniformity of quality of a product, of the life span of individuals — whether human beings, telephone poles, or metal culverts — constitutes one of the most fundamental developments in the history of the growth of scientific methods. Its uses are of just as much value in the industrial and commercial world as in the scientific laboratory.

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and furnace cooled after 3 hr. at 1,275° F., gave the following transverse tensile tests at 1 in. and 1.6 in. radii respectively: 82,000; 106,000; 21%; 30.8% and 86,000; 108,000; 22%; and 49.2%.

Coarse ingot structure is much more pronounced at the quickly chilled muzzle end. Also the test coupons taken from the molten bath showed similar structure around the edges where the metal was chilled very quickly. It was decided to pour another casting at a slower rate. Casting C-209 was therefore made by pouring the metal into the mold in 77 sec. instead of 24 sec. Slightly more zirconium was also added to this heat, but the change in rate of pour did not seem to affect the macrostructure at all. Sections 7 in. long were again taken from breech and muzzle ends and treated according to the program last mentioned (except time at heat was increased to 4 hr.).

Strength was satisfactory but the ductility and Charpy tensile values were erratic and low. A few of the fractures still exhibited traces of the silvery spots. Possibly the soaking time at heat was not quite long enough.

Another casting, C-218, was then made, using a heat to which a total of 69 points of zirconium was added. Macro-etched discs 2 in. in from breech and muzzle ends, shown in the figures on page 38, disclose an excellent macrostructure at breech but again the typical coarse grain at the muzzle. Sections, each 6 in. long, were taken from breech and muzzle ends and treated as follows: 2,100° F. for 3 hr., air cool; 2,012° F. for 3 hr., air cool; 1,607° F. for 3 hr., water quench; 1,290° F. for 4 hr., furnace cool. Discs taken from four sections after the quench showed none of the coarse-grained structure.

After the draw, test bars taken on different radii from the center of the sections gave the results tabulated.

Microstructure shown on page 39 shows fine uniform sorbite with some ferrite evenly distributed in small dots. There appears to be no segregation. The breech, as is to be expected,

is slightly coarser than the muzzle. Compared to the micro on page 37, the casting at the muzzle end appears to have a somewhat better structure than the heat treated forging.

It should be pointed out that test bars taken on the 1-in. radius are in metal that would be removed from a gun tube casting before it goes into service. Disregarding these inner bars, which should be done for the purposes of

TRANSVERSE TESTS ON HEAT TREATED GUN TUBE C-218

End and Radius	Proportional Limit	Tensile Strength	Elongation	Reduction in Area	Charpy Tensile Impact	Brinell Hardness
Breech, 1 in.	58,000	94,000	20.0	27.4	23.6	
	68,000	94,000	15.0	26.0	27.1 , 15.5	
Breech, 2 in.	66,000	90,000	25.0	48.6	30.1 , 31.8	179
	60,000	90,000	25.0	56.8	30.4 , 34.0	
Breech, 3 in.	66,000	90,000	27.0	63.2	40.5	
	68,000	92,000	25.0	55.2	37.1	179
Muzzle, 1 in.	74,000	96,000	11.0	18.4	17.2 , 15.2	
	74,000	96,000	13.0	28.1	13.0	
Muzzle, 1.5 in.	76,000	102,000	24.0	50.4	28.6	
	76,000	100,000	23.0	56.8	32.9 , 28.3	187

appraisal, the other test specimens meet the requirements, and are entirely satisfactory.

Centrifugally cast guns containing normal manganese show structure and physical properties equivalent to forgings of equal composition and size. The low-manganese castings maintain this distinction in a remarkable degree, even at the inferior-appearing muzzle end.

In strength and ductility the castings, when properly treated, have responded as well as the forgings.

The physical properties, except the low Charpy on the large ingot, No. 263, after moderate reduction in the press, compare favorably with those of similar alloy steels containing normal manganese. Penetration of hardening throughout the heavier pieces was about the same as would be expected from ordinary alloy steel with normal manganese and equivalent carbon content. During the tests a number of drastic water quenches were made and no tendency to checking or cracking was noted. After proper treatment had been applied, nearly every tensile test bar exhibited the fibrous, cup-and-cone type of fracture characteristic of high quality steel. No surface imperfections indicative of dirty steel could be found.

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By Nelson Littell
Patent Attorney
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New York City
Member A.S.S.T.

reviews
of
Recent
Patents

Welding Rod, *by Frank A. Fahrenwald, Chicago, assignor to American Manganese Steel Co. 1,815,464; July 21.*

This rod for welding manganese steel has wide range of composition but the preferred formula lists iron, 80%; manganese, 14%; carbon, 1.30%; nickel, 5% and silicon, 0.35%. When the rod is melted and applied it exhibits the essentials of heat treated manganese steel such as toughness, ductility, resistance to abrasion and hardening under cold work. The high nickel content overcomes any tendency of the metallic manganese to oxidize and prevents embrittlement under slow cooling.

Electrode Holder, *by William H. Walter, Cynwyd, Pa. 1,809,656; June 9.*

The bracket 1 is provided with a terminal plate 3 which is secured to the bus bar and the bracket is provided with the opening 4 through which the electrode is inserted. A cooling coil 7 may preferably be used to protect the parts
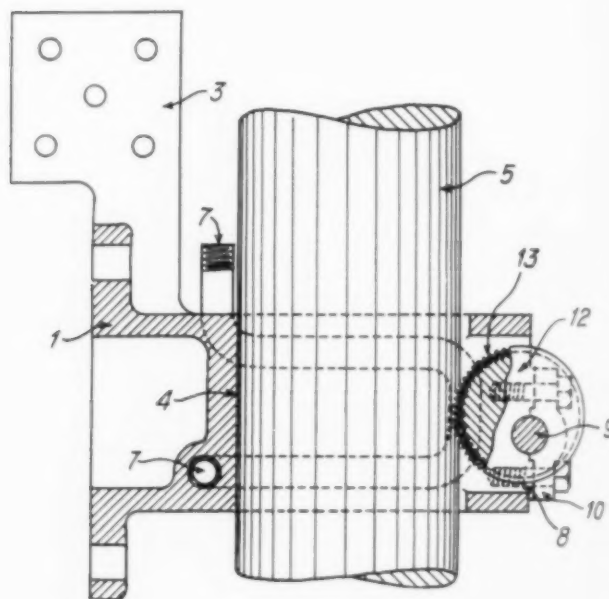
from excessive heat. The front end of the supporting bracket is provided with a half bearing 8 for receiving a shaft 9 which is retained in position by a pair of bearing caps 10. An eccentric 12 having a serrated surface 13 is secured to the shaft 9 and is adapted to rotate therewith. The ends of the shaft 9 are squared for receiving a wrench or crank by means of which the shaft can be rotated to engage or release the electrode. As the eccentric is concave in form it will engage the electrode 5 and as the electrode passes downwardly it will engage the serrated portion 13 to form a wedge.

Pickling Process, *by Deal. H. Tompkins, Nitro, West Virginia, assignor to the Rubber Service Laboratories Co., Akron. 1,808,184-5-6.*

These patents describe inhibitors to prevent excessive pickling and embrittlement of metal. Each of the patents describes a separate product which may be added to a suitable pickling solution and in one patent the product is described as a small proportion of a sulphuric acid derivative of a reaction product of sulphur dioxide and an aldehyde-amine product.
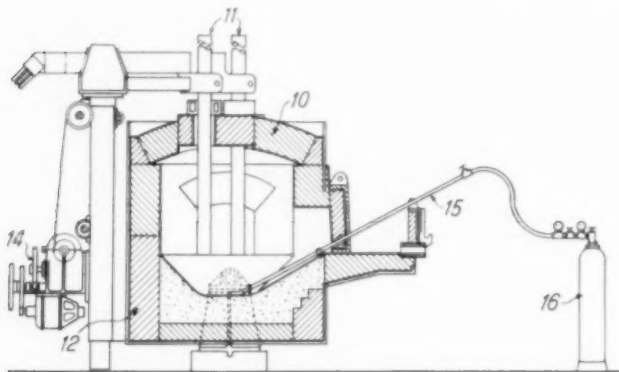
HEAT–use
LITE
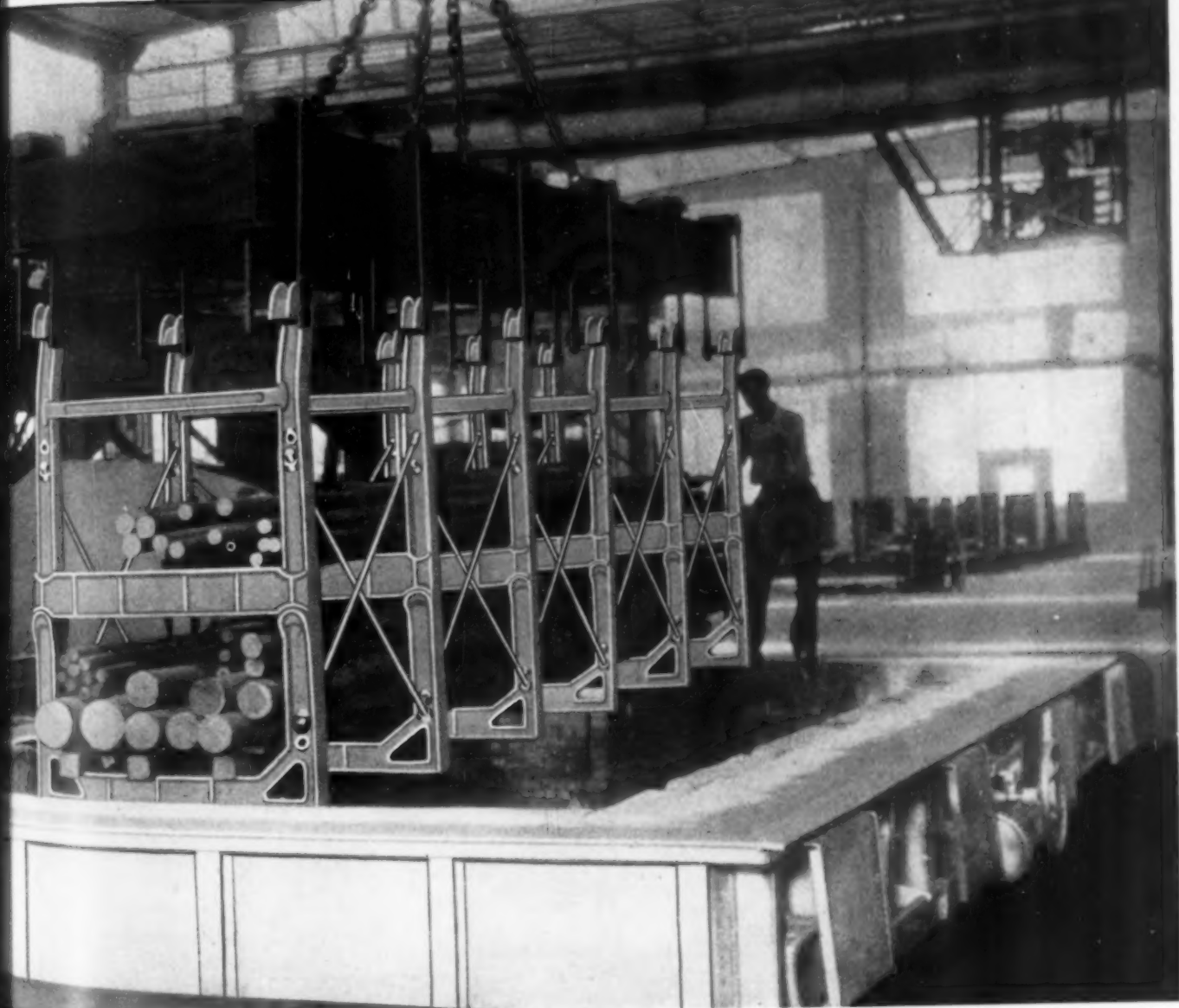
Metal Purifying, *by Charles W. Carman, Washington, Pa., assignor to Stainless Steel Corp. 1,809,436; June 9.*

The electric arc furnace *10* may be heated with either single or polyphase electrodes *11,* and the lining *12* may be either acid or basic. A suitable mechanism *14* controls the position of the electrodes. A hole *15* is drilled in the

side of the furnace to receive the pipe *15* which extends to an oxygen bottle *16,* and during the operation the charge will be melted at a temperature of about 3,100° F. and be in a condition for purifying. The pipe *15* which is preferably a chrome-nickel base alloy is introduced to the bottom of the molten bath and under sufficient pressure to overcome the head of molten metal the oxygen was allowed to escape, causing a bluish flame and then one with a yellow hue. After the injection the pipe is withdrawn.

Metal Treatment, *by Orin A. Bassett, Oklahoma City, Okla., assignor to National Industrial Laboratories Corp. 1,811,909; June 30.*

Metallic articles, particularly those which are inherently fugitive by reason of relatively low melting point or ready oxidizability, are treated. Potassium cyanide, borax, sodium carbonate, or graphite may be applied to approximately a thickness of $\frac{1}{8}$ to $\frac{1}{2}$ in. depending on the size of the article. As the article is heated and quenched it will be found that the zinc coating will be found intact and capable of taking a superior polish. The steel article may be annealed or may be heated for bending and in fact needles of tin or galvanized iron wire can be made and tempered to any desired hardness.

Read Maytag's Experience
with a G-E Mesh-belt Conveyor Furnace

THE MAYTAG COMPANY
NEWTON, IOWA

June Eleventh
1 9 3 1

General Electric Company
Davenport
Iowa

Att: Mr. K. A. Hills

Gentlemen:

Our primary reason for
installing the General Electric Mesh Belt Conveyor Furnace was to improve the quality of
our product, and not particularly to lower production costs. Since the installation of the
furnace, the quality of our drop forgings has
increased about 100%, and it has decreased our
labor costs about 50%.

The furnace is used to
heat treat the nickel alloy steel crankshafts
of our multi-motor engines. Production averages approximately three hundred pounds per
hour.

The performance of the
G. E. furnace has been entirely satisfactory.
It has accomplished the purpose for which it
was installed, - the improvement of the quality
of our production.

Yours very truly

THE MAYTAG COMPANY
Factory Manager

W.A.Smith-RD

IF you are using two or three batch-type furnaces to heat-treat miscellaneous small steel parts, it may actually pay you to replace them immediately with a fast, automatic, highly accurate G-E mesh-belt conveyor furnace. Ask your nearest G-E office.

The G-E mesh-belt conveyor furnace at the Maytag Company's plant, Newton, Iowa. By greatly improving the quality of a single part of the washing machines, it has helped to add lustre to a good name
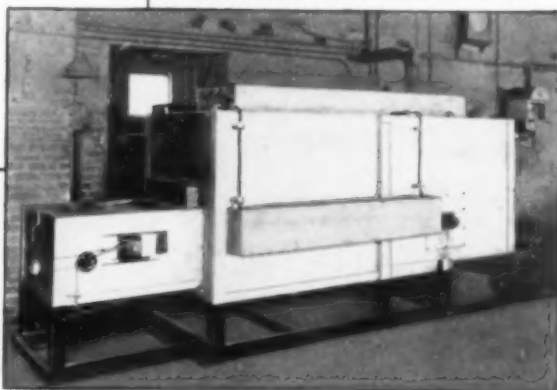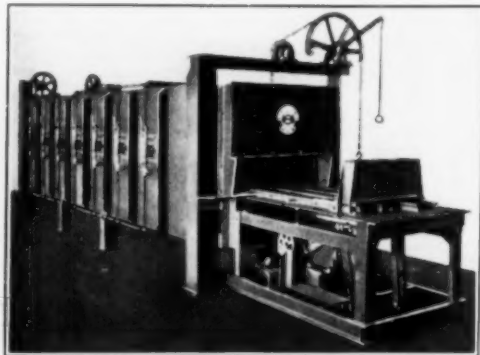
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SALES AND ENGINEERING SERVICE IN PRINCIPAL CITIES

Treating Car Wheels, *by Elmyr A. Laughlin, Rockvale, Ill. 1,811,203-4; June 23.*

These patents relate to the method and apparatus for treating car wheels by which the steel car wheel may have a tread surface adapted to withstand the normal wear thereon, and the interior or body portion will be especially adapted to withstand the shocks and jars to which they are subjected in use. The method consists in employing a wheel of steel having a carbon content of from .35 to .45 with the usual silicon and manganese content allowable. After the wheel is properly formed it is heated rapidly to above the critical range or around 1,600° to 1,700° F. It is then quenched with water at a temperature of from 70° to 80° F., subjecting the entire exterior surface to the quenching fluid uniformly and simultaneously for a period of time of from 10 to 20 seconds. The internal heat will then diffuse substantially uniformly until the exterior surfaces of the wheel will be reheated to a temperature of from 1,200° to 1,500° F. A second quenching is confined solely to the tread portion of the wheel and continued for a period of from 3 to 10 minutes or until the body has been sufficiently cooled so that when the interior heat is again diffused the temperature of the whole body will have been reduced to a drawing temperature around 500° F. The tread surfaces of such wheels are twice as hard as the heads of the rail, and the steel wheels of 500 pounds are strong and durable.

Thermit Steel, *by John H. Deppeler, Weehawken, N. J. 1,815,052; July 21.*

An improved thermit steel involving high ultimate strength without the usual decrease in ductility is described, the improved qualities of the steel being due to the presence therein of manganese, carbon and aluminum within prescribed limits. Increasing quantities of manganese, with and without increasing percentages of carbon and with a small percentage of aluminum, were developed and with the increase of quantity of manganese, the measurements of tensile strength and elongation showed that these thermit steels passed through a critical stage in which the manganese content varied from .40% to .50% and that with the higher percentage of manganese, for example, .65% to .70%, the physical properties were greatly improved.